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TECHNICAL REPORT
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TEMPERATURE DISTRIBUTION AND EFFECTS OF INSULATION AND NIGHT-TIME VENTILATION IN AN ARMY WAREHOUSE

by

William L. Porter

and

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January 1971

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Food Laboratory

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Foreword

During 1956, 1957 and 1958 a study of the possible beneficial effects of night-time ventilation of warehouses used for food storage was conducted at the Richmond QM Depot by the then Environmental Protection Research Division, Quartermaster Research and Engineering Center, Natick, Massachusetts.

Cooling effects were found, but because of an insufficient supply of ventilating fans and inadequate air intakes, it was concluded that further study was needed to justify any large scale warehouse modifications. These findings were disseminated by letter to the affected agencies

However, a large body of data on temperatures in warehouse air and in food cartons under varying conditions was accumulated In response to a large demand for storage temperature data, this was reduced to tables and graphs showing means, absolute maxima, and temperature distribution by months and for the total period. A highly significant correlation between the monthly means of storage temperatures and of outside air temperatures was found.

These data and conclusions are reported herein, together with an analysis of the frequency of beneficial ventilation conditions and the effect of reflective insulation and ventilation on warehouse temperatures.

The observational work was performed in 1956, 1957, and 1958, and data reduction and analysis was carried out in 1963 and 1964 at the US Army Natick Laboratories.

The work was performed under project 1KO-14501-A71C, Food Research, and 7-83-05-004A, Environmental Requirements for Design of Military Items.

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Abstract

This report contains the detailed analysis of the frequencies, means and standard deviations of temperature observations made at sixteen positions in the storage area and in food containers in two bays (non-ventilated and night ventilated) of an Army warehouse at Richmond, Virginia, during a three year period

Hourly temperatures at all points are reported for several selected hottest days.

Temperature distributions by months and for the total year at each position are given in tabular and graphical form Thus, if an empirical temperature degradation relation is known for a given food, the expected storage life at this warehouse may be predicted.

Storage monthly mean temperatures were found to be highly significantly correlated with outside air mean temperatures, facilitating prediction of effective mean storage temperatures for laboratory simulation where only ambient data are known

The work of Dr. Arthur V. Dodd of Earth Sciences Laboratory has demonstrated that similar predictive relations hold between mean storage air and mean warehouse air temperature for 15 US Army warehouses of various types and locations Therefore, storage life predictions may be made for other warehouses if the food degradation-temperature relationship is known.

Using only two one-horsepower exhaust fans, the effect of combined night air ventilation and insulation was shown to be somewhat small (4.25 F° difference in mean storage air temperature) but for one year 18% increase in storage life of an average food would be predicted as a result

It was predicted that the installation of more fans would greatly increase the cooling and resultant food storage life. Increasing the horsepower without increase in number of fans would be less effective

Introduction

A Purpose and Scope of the Study

This is a detailed study of the temperature regime at selected points in a typical Army warehouse at Richmond, Virginia, with and without insulation and ventilation. Air temperatures and humidities were measured inside food cartons, in the open warehouse, and in the outside air, both under normal operating conditions and under conditions imposed by reflective ceiling insulation with or without moderate forced night-time ventilation.[1]

The study, which was conducted during the period 1956 to 1958, was undertaken by the then Environmental Protection Research Division to discover possible methods of lowering average air and food temperatures in Army packaged-food warehouses and what the effects of this would be. It was initiated at the request of the then Chief[2], Care and Preservation Section, Field Service Division, Office of the Quartermaster General, and the Commandant, Quartermaster Food and Container Institute for the Armed Forces, following the Warehouse Ventilation Conference held 15 September 1954, at the Office of the Quartermaster General.

A summary report was submitted to the requesting agency in May 1958. The present detailed report is the result of much more

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[1]It should be noted that the Richmond installation is now designated the Defense General Supply Center, but it continues to have a limited food storage mission

[2]Chief of the Section at that time was the late George W. Kitzmiller.

extensive data analysis made possible now by the availability of computers at Natick Laboratories. It was stimulated by many requests for precise warehouse storage temperature data, and the greatly increased importance of the Richmond installation, currently the Defense General Supply Center.

An additional purpose of the present study was to develop a method of predicting effective food storage temperatures and expected storage life in warehouses where only climatic statistics and a relation between food degradation and temperature are known

B. Nature of the Problem

It has been established (1) that for sterile degradation the logarithm of reaction rates in foods in cans (as indexed by retention of certain essential vitamins) increases in an approximately linear relationship with increase in temperature of storage The relationship for many foods in normal ranges of temperature may be roughly described by

$$\log y/y_o = 0.0167(T-T_o)$$

where y = reaction rate at T (^oF)

y_o = reaction rate at T_o (^oF)

T = constant storage temperature or effective mean storage temperature (^oF)

T_o = storage temperature at which reaction rate is known

In foods, reaction rate may be conveniently described by its inverse, the storage life to some arbitrary level of a nutritional

constituent or of acceptance by a flavor panel. Reaction rates are, of course, more accurately represented by the Arrhenius equation (2), but the above is quite adequate for work with foods

This relationship predicts that a decrease of 5 F° in storage temperature will result in a 21 percent increase in storage life, while 10 F° will result in a 47 percent increase. This may result either from constant storage temperature conditions or from storage at cycling temperatures, whose effective storage temperature is the same (see infra, Section IIID) Therefore, any lowering of warehouse mean temperatures, (particularly in the 70° to 100°F temperature range) results in substantial gains in storage life of canned foods Feaster, Tompkins, and Pearce state that a storage temperature of 70°F or below is desirable, since storage below this temperature has been found to favor quality and vitamin retention in canned foods (3). It should be emphasized that 70°F is not a critical boundary, but that aging reactions proceed at noticeably slower rates when air temperatures in the storage area are less than 70°F

Army canned food is often stored for periods exceeding two years. Although some method of reducing air temperatures in warehouses is indicated, up to the present it has been decided that for many items of the B and C ration, large expenditures for mechanically-refrigerated storage could not be justified economically in terms of gains in storage life. Therefore, methods were sought by which lowering of mean temperatures could be more cheaply effected by

controlled night-time ventilation, daytime sealing and insulation, or other means short of mechanical refrigeration.

C. Previous Work on Warehouse Temperatures in Predecessor Offices of the Environmental Protection Division

Using data collected in Army warehouses in 1949 (4), comparative mean daily temperatures in warehouse air and in outside air were tabulated for each month for a period of one year at each of the major Army warehouses[1] Frequency of various relative humidities in the warehouses was also compiled. Figs. 1-4 illustrate the comparative mean daily inside and mean daily minimum outside temperatures by months for four warehouses which show large differentials between mean daily temperature of warehouse air at the 15 foot level and night-time mean daily minimum outside air temperature. This differential is the upper limit of possible reduction of mean daily warehouse air temperature which might be accomplished by night-time forced ventilation and theoretically-complete daytime sealing and insulation. Table I shows these limiting values for all Army warehouses In practice, one-half this reduction is probably all that can be achieved, under optimum conditions.

To discover which warehouses were located most favorably for application of night-time ventilation, two maps were prepared (Figs. 5-6). These maps indicate, at each warehouse location, the

[1] It should be noted that some of the warehouses discussed in this report have been deactivated or no longer have a subsistence function, whereas some food storage now occurs in warehouses not mentioned here.

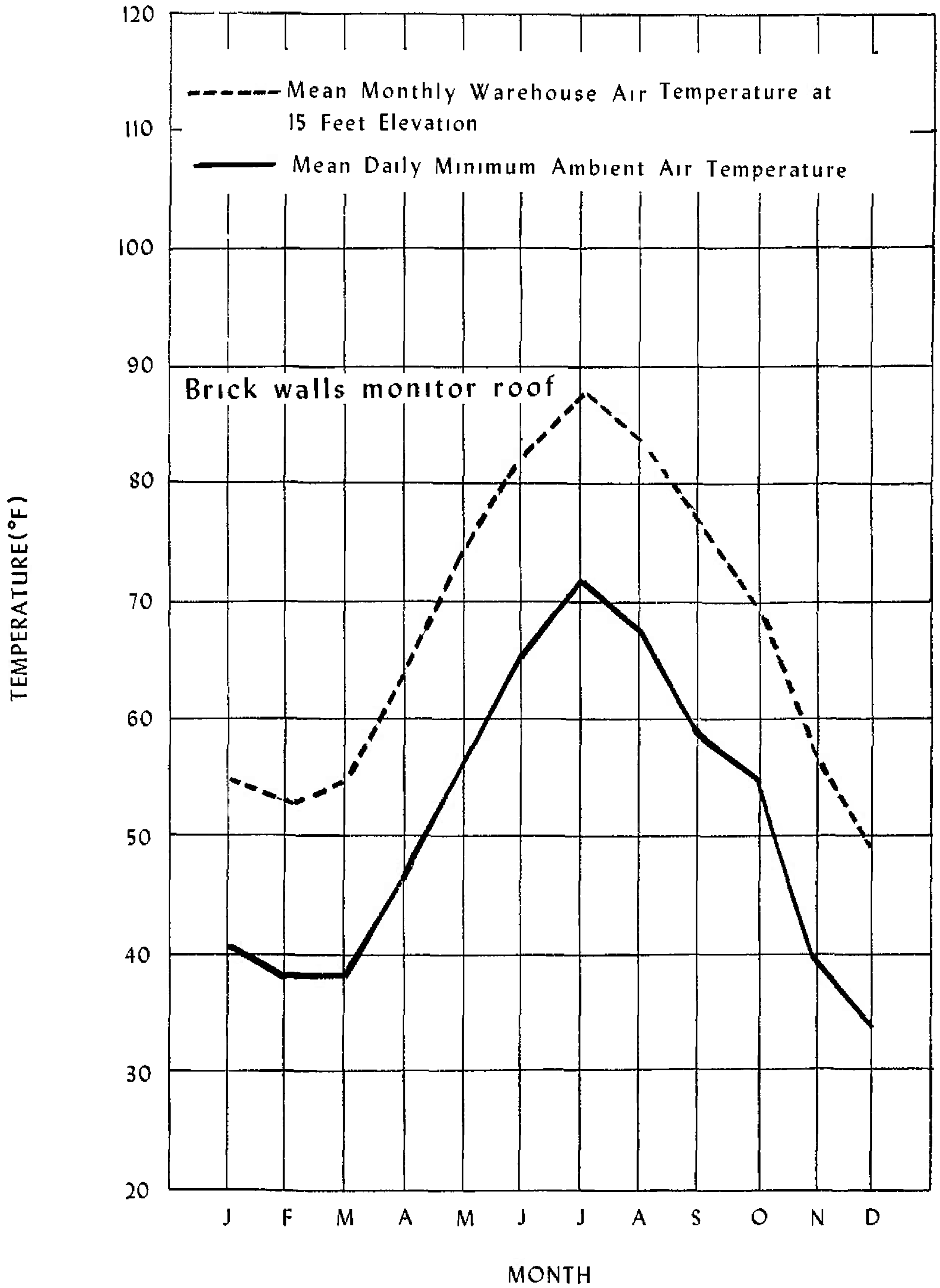


Figure 1 Mean daily warehouse and mean daily minimum outside air temperatures at Richmond Depot.

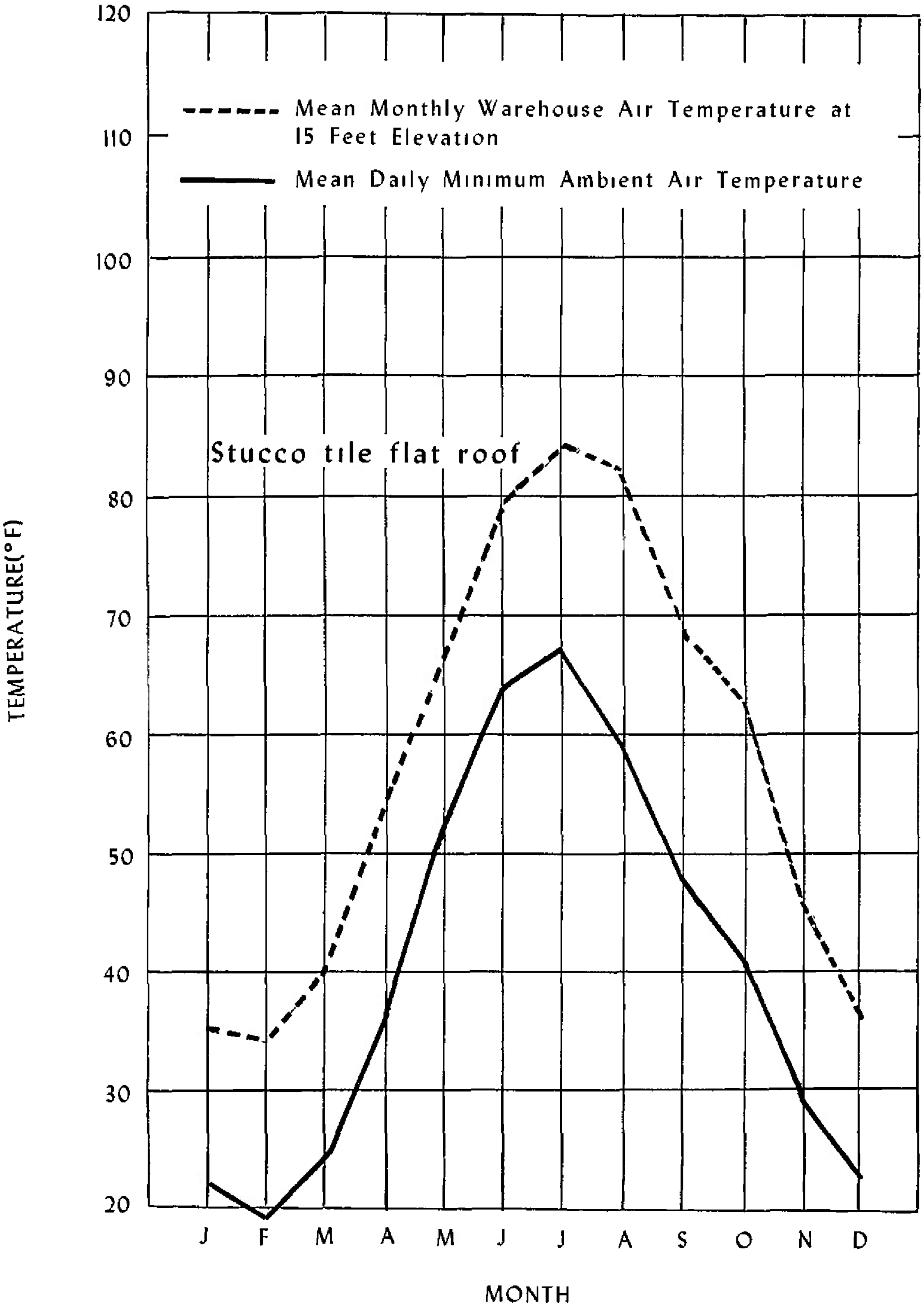


Figure 2 Mean daily warehouse and mean daily minimum outside air temperatures at Schenectady Depot.

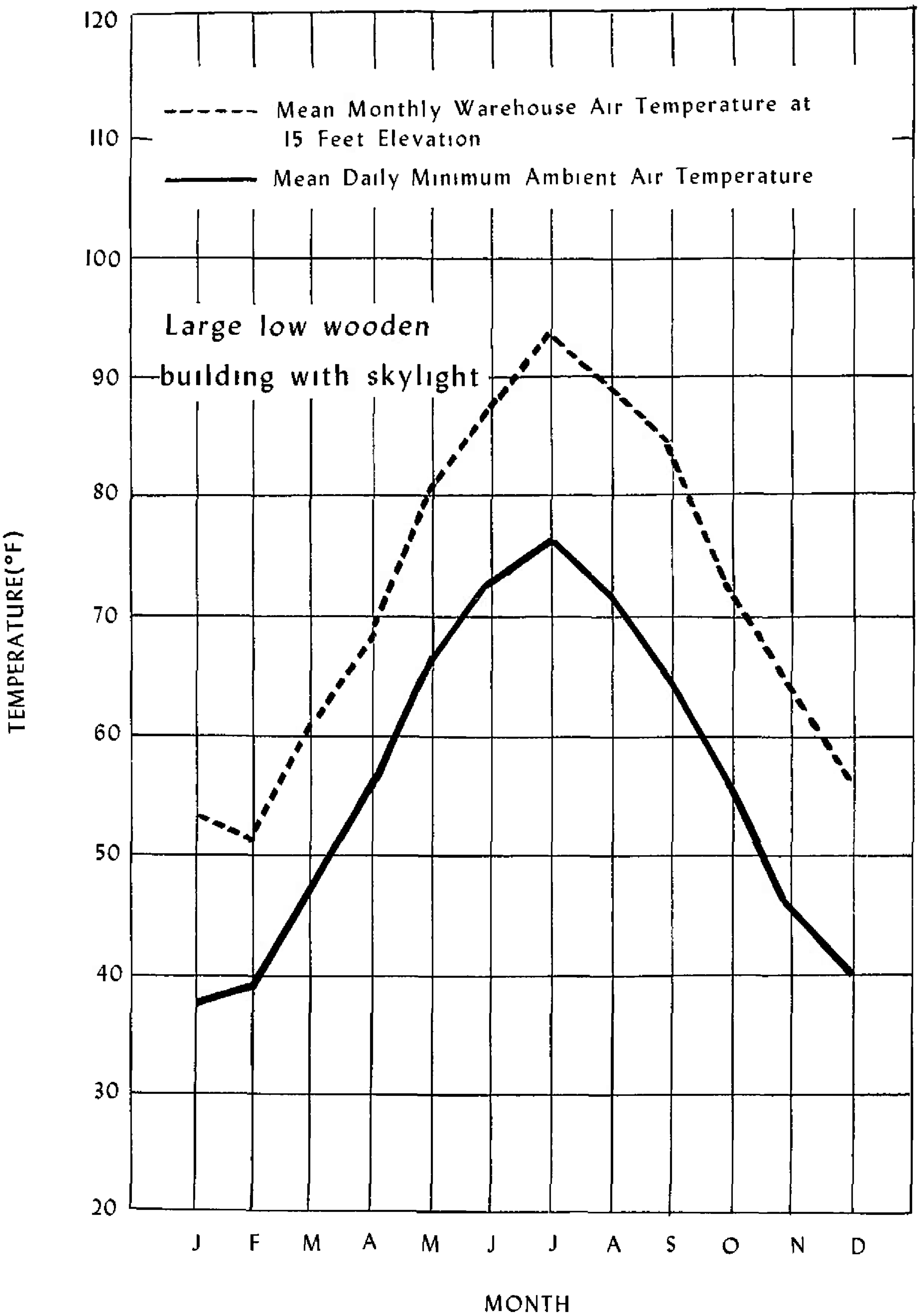


Figure 3. Mean daily warehouse and mean daily minimum outside air temperatures at Fort Worth Depot.

Figure 4. Mean daily warehouse and mean daily minimum outside air temperatures at Sharpe Depot

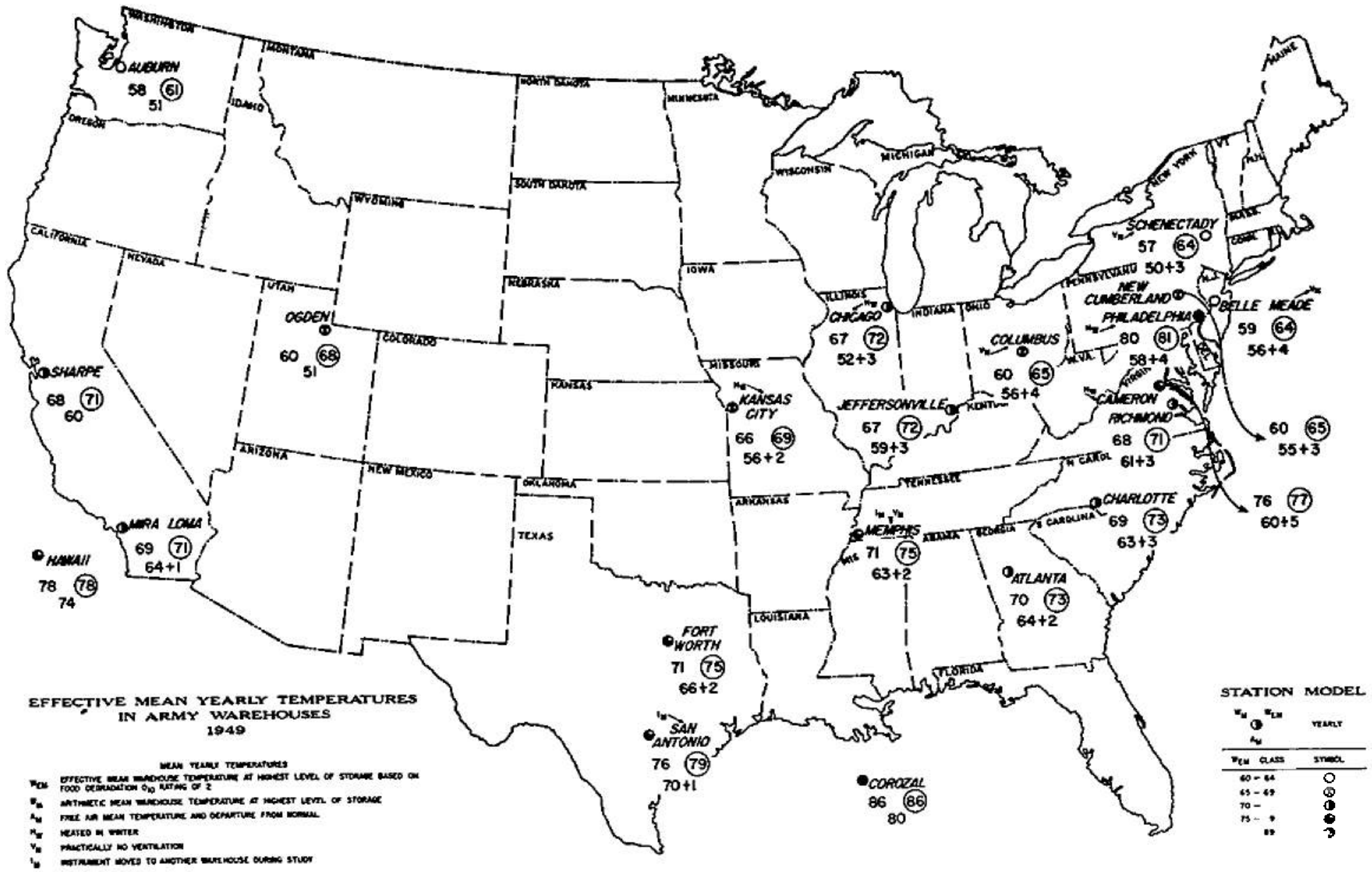


Figure 5. Effective mean yearly food storage temperatures in Army warehouses. See text for method of derivation

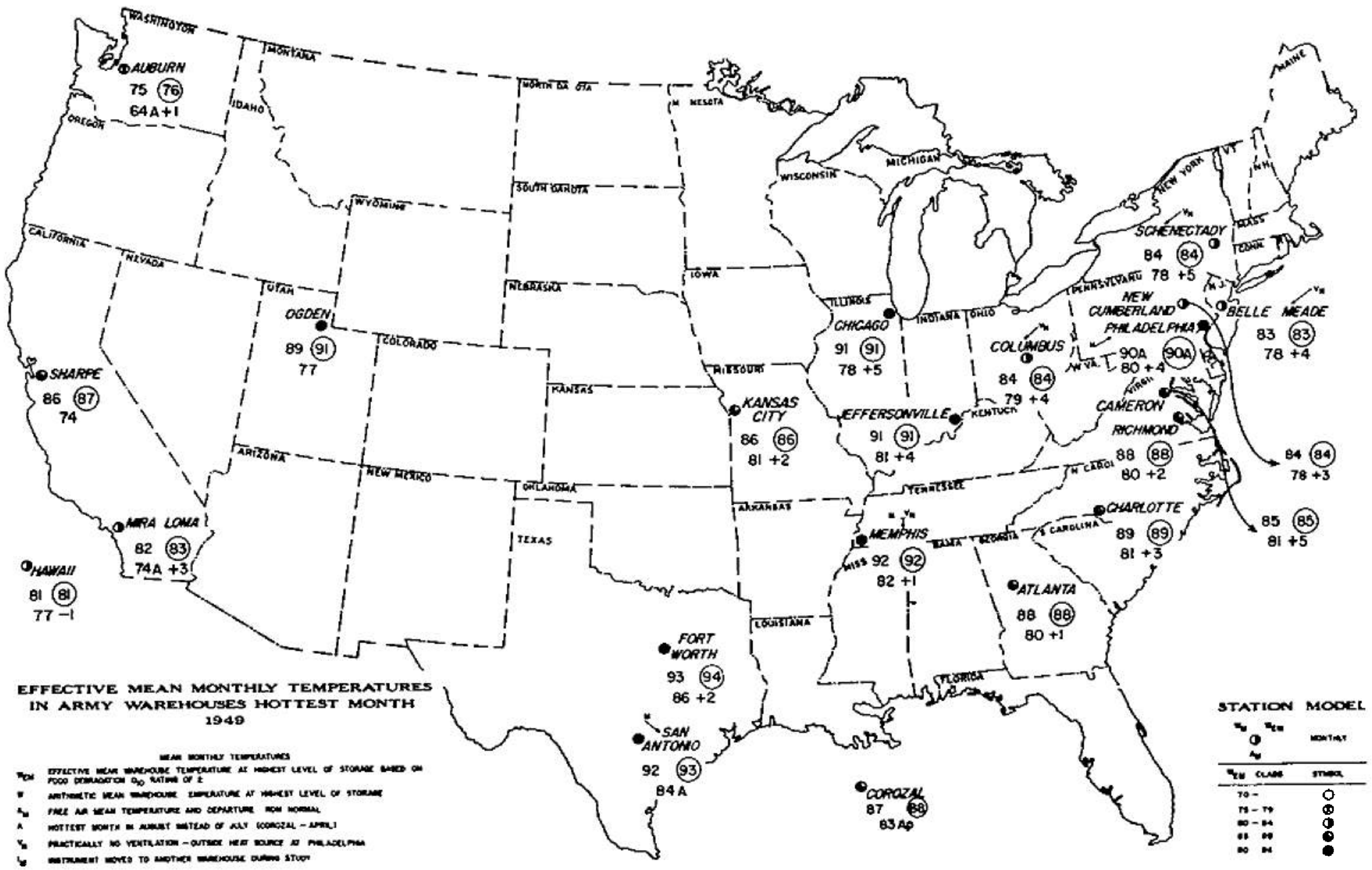


Figure 6 Effective mean monthly food storage temperatures in Army warehouses - hottest month See text for derivation

Table I. Estimated Amounts of Cooling Possible by Controlled Ventilation of Army Warehouses[a]

Warehouse	July mean minimum temperature (°F)		Maximum possible cooling in unsealed warehouse (F°)	Theoretical maximum cooling in perfectly insulated warehouse (difference between July mean warehouse temperature and July mean minimum free air temperature[a]) (F°)
	Free Air	Warehouse[b] (15 foot level)		
Sharpe[c]	55	77	22	31
Ogden	62	75	13	27
Auburn	53	65	12	22
Memphis	74	86	12	18
Fort Worth	76	84	8	17
Schenectady	67	79	12	17
Atlanta	72	82	10	16
Richmond	72	82	10	16
New Cumberland	69	77	8	15
Kansas City	72	84	12	14
Columbus	70	77	7	14
Belle Meade	69	78	9	14

[a]These estimates are based on the assumption that if a warehouse is force-ventilated at night and tightly sealed and well insulated from heat accumulation during the day, its mean daily temperature at the upper level of storage will approach the free air minimum temperature to a degree dependent on the efficiency of ventilation and insulation (5).

[b]Data are from Reference 4.

[c]Underlined warehouses are those for which data is shown in Figs. 1-4

arithmetic mean and effective mean temperature for the hottest month and for the entire year of observation in the 1949 warehouse temperature study The mean daily temperatures of outside air were also shown for comparison The correction for effective mean temperature is added to the arithmetic mean to yield a constant temperature, the effective mean, which will produce the same aging effect on most foods as the fluctuating temperatures of actual storage for the same period Used in conjunction with Table I, these maps indicate the warehouses at which mean temperature reduction by ventilation will most increase storage life of foods. This is dependent upon both the level of effective mean temperatures for the hottest month and the possible reduction of that mean.

A nearly linear relationship between mean weekly and monthly carton air temperature and mean weekly and monthly outside air temperature had been found for boxcars (7) and storage dumps (8), and roughly, for mean annual warehouse air temperature and mean annual outside air temperature (1).

This suggested that a detailed study of carton temperatures in warehouses should yield a reliable method for predicting food temperature and storage life based on mean monthly outside temperature. Such a relationship and method was indeed found, based on 23 months of observations, and reliable predictions of carton air temperature means and frequencies are now possible

D. Background Information from Sources Outside U.S. Army Natick Laboratories

1. Interviews with Experts in the Field on Food Storage

a The late Dr. B. E. Proctor (then Chairman, Department of Food Technology, Massachusetts Institute of Technology) stated that, to his knowledge, no element of the civilian food industry stores semi-perishable canned food without refrigeration for long periods (two to three years). He added that the food storage problem of the Army is, therefore, unusual and requires unusual solutions.

b. Professor A. L. Hesselschwerdt (Professor of Mechanical Engineering, Massachusetts Institute of Technology), an authority on food refrigeration, was also unaware of any civilian food industry which stores canned foods for such long periods, or which uses ventilation rather than refrigeration practices in conjunction with such storage.

c. The late Dr. S. C. Prescott (then Emeritus Professor, Department of Food Technology, Massachusetts Institute of Technology), a leading figure in food processing and storage work, shared the opinion that the Army's long food storage period is unusual in the food industry He had maintained for many years that canned foods should be kept in so-called "cooler" storage, i e , below 50°F, although most warehousemen move canned foodstuffs fast enough not to be concerned about this

d. Mr. George W. Higgs, Assistant Manager, Marine Corps, Supply and Naval Research Facilities Branch, Mr. Martin R. Borger, Mechanical Section, and Mr Carl J Ebert, Head, Architectural Specifications Unit, Engineering and Technical Services Division, Bureau of Yards and Docks, Department of the Navy

Mr Higgs stated that the Navy has undertaken a rather extensive program of warehouse dehumidification. In the course of this program, the Naval Supply Depot at Mechanicsburg, Pennsylvania was vapor-proofed and equipped with selective ventilation, by which a monitor mechanism was used to admit outside air during nights when the outside dewpoint was below that of the warehouse. By this means, they accomplished a measure of dehumidification (55% relative humidity is maintained) at a much lower cost than by heating, or by desiccant or refrigerant dehumidification In addition, although this program was planned for a sealed or so-called "inactive" warehouse with entrance by double door vestibule, it had achieved substantial results even with moderate warehouse activity and no entry vestibules, a situation comparable to that which would of necessity prevail at Army food warehouses. Messrs Borger and Ebert believed that this selective control device could be successfully adapted to temperature control through the admission of air of suitable temperature and relative humidity.

It was the opinion of Messrs. Borger and Ebert that conversion of the selected Army food warehouses for both heat insulation and vapor-proofing, in order to enhance the effects of night-time ventilation, might be costly, and should be undertaken only after the effects of ventilation had been investigated without such conversion.

e. The late Mr. George W. Kitzmiller, then Chief, Care and Preservation Section, Field Service Division, Office of the Quartermaster General, Washington, D. C.

Of particular relevance to the application of forced night-time ventilation to Army subsistence warehouses are certain practical aspects of warehouse operation, as suggested by Dr. Kitzmiller and outlined in the following paragraphs.

First, the controlling factor in long-term storage of canned food is usually the location of the depot with respect to the posts, camps, and stations which it supplies and not the possible advantages of a cooler location.

Second, as a corollary, neither depots nor individual warehouses at depots are usually ear-marked for specific use in food storage. Thus, although food storage has a top priority, it may be displaced for other storage at any warehouse of any depot.

Third, the nature of warehouse construction, with extensive entry doors on each side, and the continued activity of long

tractor trains in and out of each section, does not favor daytime sealing, entry vestibules, or insulation to conserve cool air admitted at night It is, however, possible to designate active and inactive subsistence sections. Canned goods from the inactive sections, relatively well sealed, can be moved through the warehouse at infrequent intervals to the less protected active section, from which frequent supply withdrawals can be made In effect, the active section becomes a warm-up vestibule, serving the two-fold function of protecting the bulk of the canned food from frequent exposure to warm daytime outside air, and in addition providing a temperature adjustment period to prevent possible condensation on cool cartons moved immediately into warm, moist outside air.

Fourth, extensive modifications for sealing certain sections of warehouses, in connection with ventilative cooling, also require the use of electrically driven stock-handling apparatus, instead of the currently used gasoline vehicles, because of the obvious exhaust fume hazard, during periods when ventilation is not desirable. It is quite possible that this hazard would also prevent the extensive allocation of inactive sections, unless the potential benefits of cooling justified the additional expense of electric vehicles

2. Survey of Literature of Heating and Ventilation

a. In the search for information regarding warehouse ventilation practices prior to the study, the following periodicals

were searched for the twenty years 1934-1954:

Transactions of the American Society of Heating and Ventilating Engineers.

Heating and Ventilating.

Heating, Piping and Air Conditioning.

Food Technology

Food Engineering (partially searched).

Although it has not been possible to make a comparable search for the period 1955-1970, some of the earlier information is cited, since it was the background for the planning of the study.

b. Uses of Night-time Ventilation

Night-time ventilation is of greatest applicability where moderate cooling is desired, and the need does not justify the expenditures required for compression refrigeration. The subject is largely discussed in the literature in terms of residential cooling, although one or two warehouse or commercial applications are reported. About 20 surveys of residential applications were reported, as contrasted with 3 commercial applications discovered.

c. Conditions for Successful Use

The practice can be used most successfully where the diurnal range of outside air temperature is great and where the structure is insulated and may be sealed during the day. Ample inlet and exhaust louvres, skylights, or windows must be available at low and high levels in the structure

Exhaust fans capable of 5 to 15 air changes per hour in warehouses and 30 to 40 air changes per hour in residences must be provided Fans are required of sufficient size and number to cool the walls of the structure as well as the inside air In one application (9) in a wax paper storage problem, ten fans spaced along the skylights were required to effect 15 air changes per hour in a space of 400,000 cu. ft., comparable to the 440,000 cu. ft. at Richmond.

Either a differential thermostat controller or an electric time control system which will actuate and cut-off the fans at specified hours is required. Recommended times of operation vary with the structure, location, and cooling requirements, but the consensus in residence cooling favors the start of fan operation about one to two hours before the outside air temperature falls to the level of the inside air temperature. This occurs at about 1900 to 2000 hours in the summer, therefore operation of the fans should commence at 1700 to 1800 and continue for the balance of the night to effect maximum reduction.

d. Advantages and Disadvantages of Night-time Ventilation

1 Cost -- Some authorities (11), estimate that the amount of cooling possible with exhaust fan night-air ventilation may be attained at a cost approximately one-half that of mechanical refrigeration

2 Temperature reductions -- In controlled experiments, a 10-20 F° lowering of afternoon interior temperature was attained in a bank with night-time ventilation and daytime sealing (11). Freyder reports an 8 to 10 F° reduction of daytime interior temperatures in a one-story office structure (10). In general, residential interior temperatures were reduced to within 2 F° of outside air temperature in the early evening hours by 30 to 40 air changes per hour. This close correspondence prevailed thereafter during fan operation. A differential of 8 to 10 F° from 2000 to 0500 hours between a fan-ventilated and a non-ventilated control house is the common average. This may be maintained or increased during the day if the structure is sealed and well insulated.

3. Moisture additions -- The introduction of cool, night-time outside air may also introduce air of high relative humidity, although the absolute humidity normally varies but little from that of daytime outside air. Adsorption of water vapor by cartons with attendant mildew, mold, carton softening or can pinholing is usually a function of relative humidity. Relative humidity will, by definition, be increased by introduction of night air of the same absolute humidity but lower temperature. The attendant deterioration might offset the benefits of increased storage life. However, the studies of Dr. J. C. Woodroof and Mr. E. K. Heaton at the Georgia Experiment Station (12) indicate that the

effects of adsorbed or condensed moisture are not critical over short periods for Combat Rations in V-board cartons. It should be noted that Silberstein (9) reported no moisture difficulty with wax paper storage under night-air ventilation Also, in discussion of Giesecke's paper, Night-air Cooling, the question of mildew and mold was raised. Geisecke stated (11) that, in his experience, moisture gained by objects experiencing night-air cooling was lost by evaporation under the higher warehouse temperatures and consequently lower relative humidities of the following day. Similarly, in the study reported herein, humidity changes caused no problems.

E. Choice of Warehouses for Study

The selection of depots for modification and study of the effect of insulation and/or forced night-time ventilation is affected by such practical considerations of warehouse operation as are mentioned above.

Were it possible to allocate subsistence storage only to environmentally favorable locations, little supplementary cooling would be necessary and the choices of warehouses for study could be simply restricted to depots of low effective mean yearly temperature, e.g., Schenectady, Auburn, and New Cumberland.

It appears that if these cooler depots were used exclusively, the costs of extra transportation would nullify the advantages of

greater storage life. Therefore, modifications for warehouse cooling must be planned within the existing pattern of depot activity and troop supply and under the assumptions that warehouses will remain relatively open and active during the day.

If it were possible to select depots for modification and study purely on the basis of a benefit-cost ratio, it seems that warehouses having the largest normal load of food stores located in western areas of large diurnal temperature range in summer, high mean temperature in the hottest month, and low mean relative humidity would most profitably repay modification. In the process of selection, consideration was given to the distribution of relative humidities prevailing in warehouses during the 1949 survey (Table II) Indiscriminate night-time cooling without dehumidification would be most hazardous in those warehouses in and around which high humidities prevail. However, as noted above, selective control devices can be used effectively to admit night-air when it is dry and cool and to exclude it when unfavorable conditions prevail.

Because of practical considerations, the warehouse ventilation study group initially chose Richmond, Sharpe, Fort Worth, and Schenectady. Warehouses at these depots have a wide range of environmental conditions and appeared likely to benefit from modification.

Table II. Two Indices of Mean Annual Humidity in Army Warehouses[a]

	Relative Humidity (%)	Vapor Pressure (mm. Hg)
Belle Meade	80 9	10.7
Corozal	79.3	22.8
Auburn	70.3	8.3
Charlotte	69 0	12 9
Hawaii	67.3	16.4
Richmond[b]	67.0	11.2
Fort Worth	66.5	13 1
Schenectady	64.0	5.1
Kansas City	63.9	9.8
Columbus	63.7	8.4
New Cumberland	63.4	8.7
Memphis	62.9	11.4
San Antonio	62.6	14.3
Atlanta	62.0	10.9
Cameron Station	61.3	14.5
Chicago	56.0	9.8
Philadelphia	55.0	14.3
Sharpe	53.0	9.3
Jeffersonville	51 0	8 9
Mira Loma	49.3	9.1
Ogden	48.0	6.4

[a]Unpublished computation of Mrs. J. H. Westbrook from Warehouse Temperature-Humidity Survey (4, 6).

[b]Underlined warehouses are those for which data is shown in Figs. 1-4.

Richmond was the first and, to date, the only depot at which the temperature regime was studied and modification was attempted.

Plan and Methods of Research

A. The Plan and Period of the Study

Two bays of Warehouse 32 of the then Richmond Quartermaster Depot were used in the study First, it was planned to measure the differential between temperatures produced in contrasting bays by insulating the ceiling of one bay, the so-called "Experimental" or "Ventilated" Bay, Bay B, and leaving Bay A, the "Control Bay", unmodified Second, the temperature differential produced by manually actuated forced ventilation of Bay B between the hours of 2000 and 0800[1] was measured. Third, the temperature differential produced between 1700 and 0800 by automatically actuated forced ventilation of Bay B with improved intake areas was measured.

Insulation had been completely installed by July 1955. The first temperature measurement period began nine months later and extended over a four and one half month period from 2 April 1956 to 17 August 1956 Manually actuated ventilation was carried on from 17 August 1956 to 16 April 1957, a period of eight months. Automatically actuated ventilation with improved intake was tested for the thirteen month period from 16 April 1957 to 12 May 1958.

[1]Eastern standard time was the time of reference for the study.

In this way, it was felt that the effect of insulation of Bay B could be separated from that of manually actuated ventilation, and these, in their turn, from that of automatically actuated ventilation, each being measured by its contrasting effect in the two bays

Throughout the study, in the ventilated Bay (B), four refrigerant dehumidifiers were operated The humidistat was set at 55% relative humidity, although it will be evident from the results that the equipment was inadequate to maintain that level at all times.

B. Methods Used in Data Gathering, Reduction, and Analysis

1. Physical Characteristics of the Warehouse, and the Two Test Bays

Warehouse 32 is located in the southeast portion of the warehouse area at an elevation of 90 feet m.s.l. (Fig 7). The installation is 10 miles south of Richmond, Virginia and west of the James River, on Highway No 1 and the Atlantic Coast and the Seaboard Railway Lines. It is ten miles southwest of the U. S. Weather Bureau Station at Byrd Field (elev. 160 ft), from which records of dry bulb and dew point temperature have been obtained as a check on data collected at the study site. No extensive water bodies except the James River separate the installation from the Weather Station.

The warehouse (Fig. 8) is of brick construction, with a steel framework supporting a monitor-type roof, and a concrete

RICHMOND DEFENSE GENERAL SUPPLY CENTER
LOCATION OF STUDY WAREHOUSE

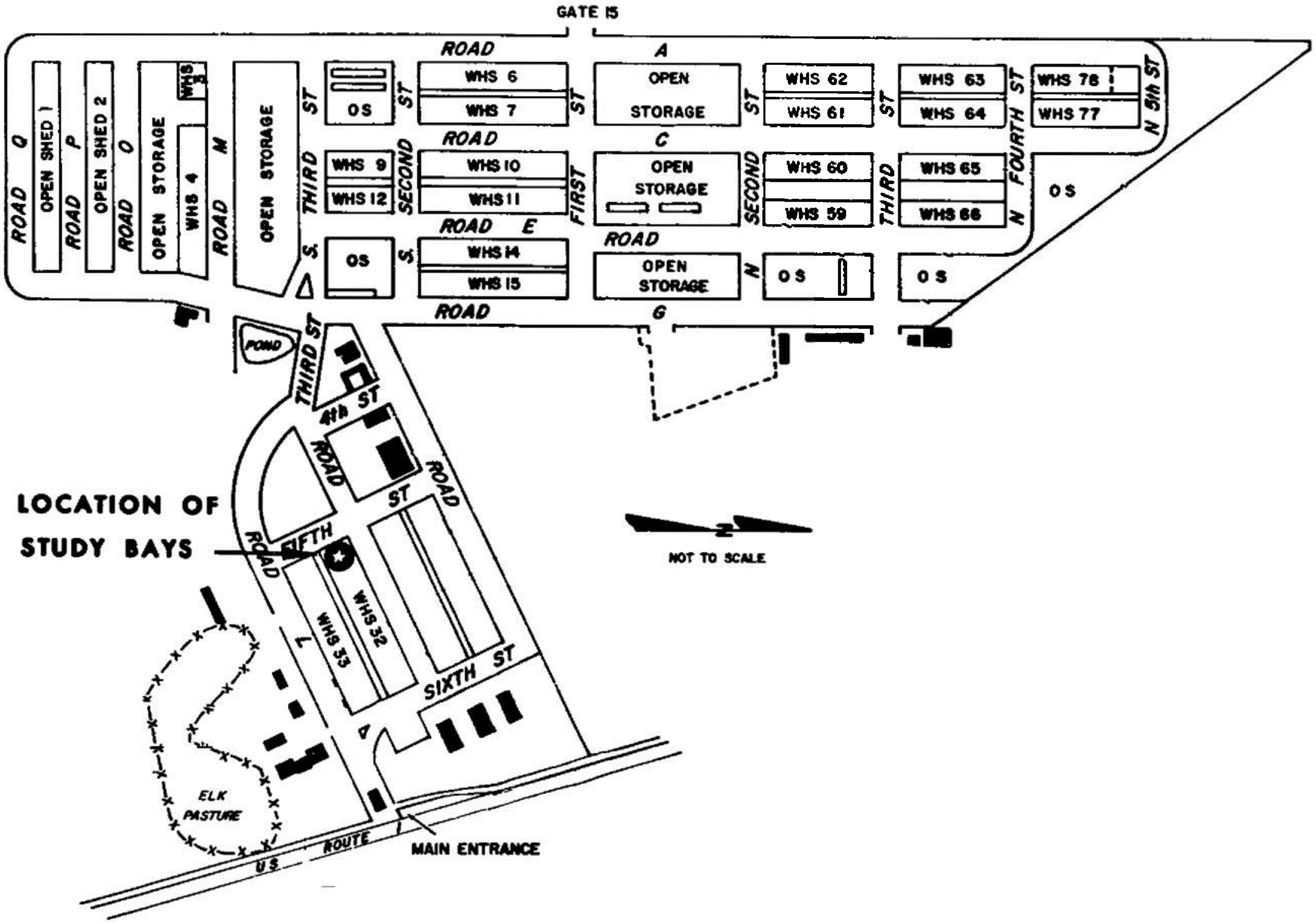


Figure 7. Location of experimental warehouse

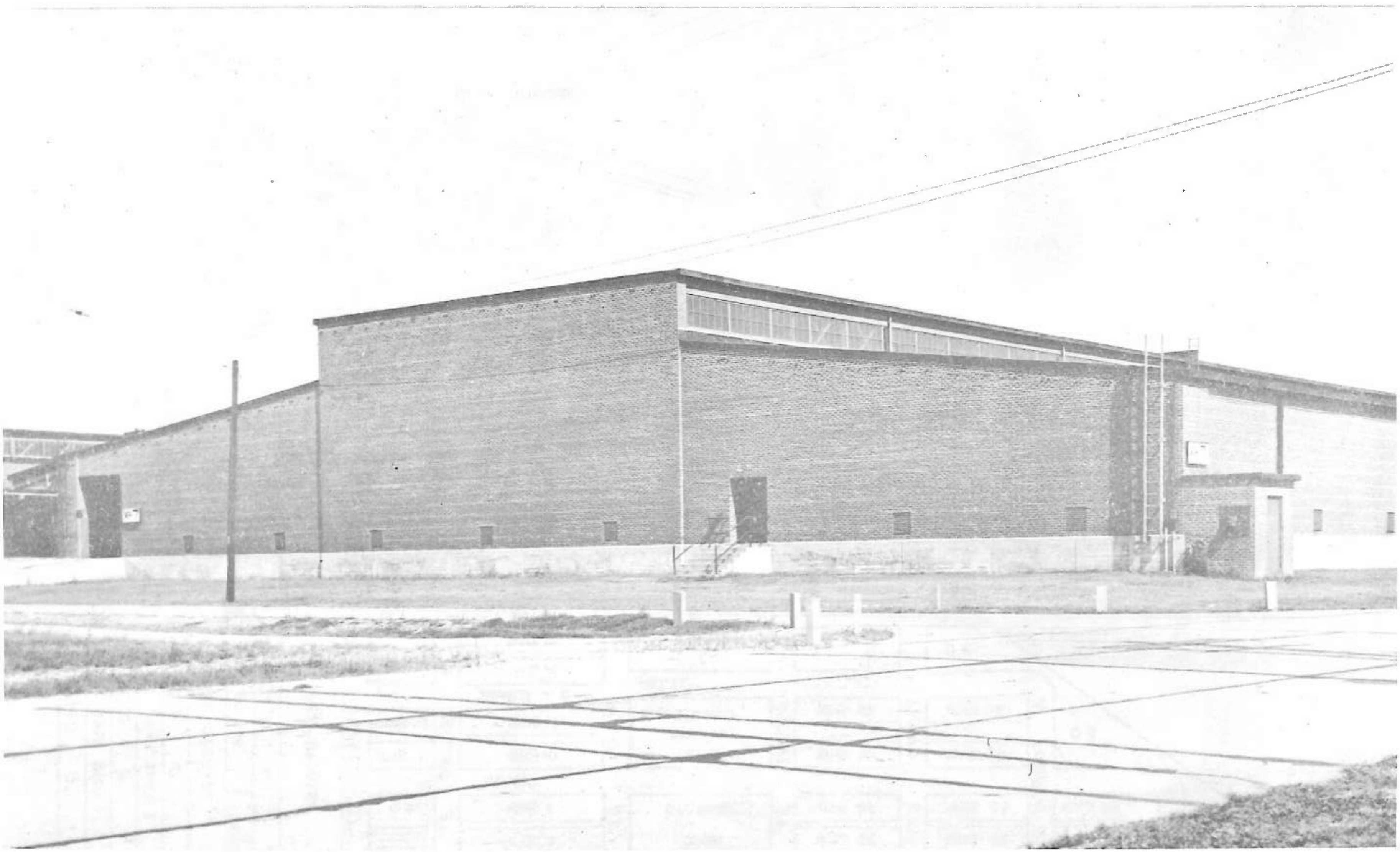


Figure 8. End elevation - Richmond warehouse.

floor. It is aligned east-northeast to west-southwest; it is 1440 feet long and 180 feet wide, and is divided by brick firewalls into twelve equal bays 120 x 180 feet in plan (Figs. 9, 10). The study bays were the western two (and at the close of the test, three) of Warehouse 32. Along the full length of the south side of the warehouse is a concrete railroad loading platform, four feet above grade, which is the standard height of the warehouse floor.

The north side of the warehouse faces a grass strip (50 ft) and a concrete road (50 ft) (Fig. 13). The roof of the warehouse is of the monitor type, the more lofty center section occupying about fifty feet of the total width. Height from floor to the ridge is 27 1/2 feet, to the inner edge of the lower roof, 20 feet, and to the outer edge, next to the brick exterior wall, 14 feet. The height of the monitor at the outer edge, where there are glass windows, is 6 feet Thirty feet from each end of the roof of the bay, along the ridge line, two modified metal exhaust ventilators are located, each approximately four feet square and containing a one horsepower exhaust fan, with automatic louvers below, which open only when the fans are running.

The air intake system consists of four louvers on the south wall, measuring two feet by two feet, and five louvers on the north wall (Fig 13) measuring three feet by two feet, located one foot above the floor of the warehouse. Permanent metal

LOCATION OF STUDY BAYS

IN WAREHOUSE

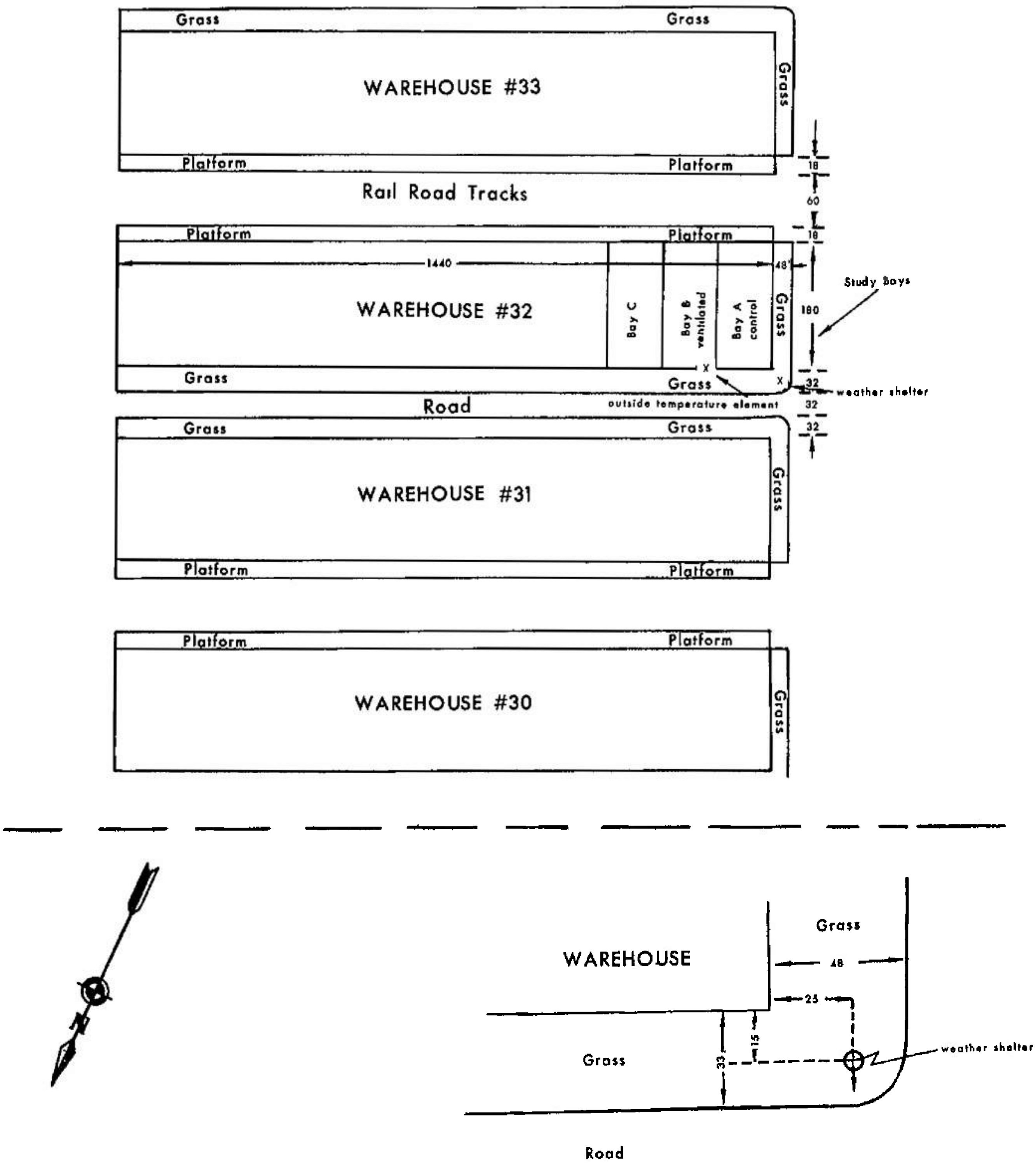


Figure 9. Location of experimental bays in warehouse.

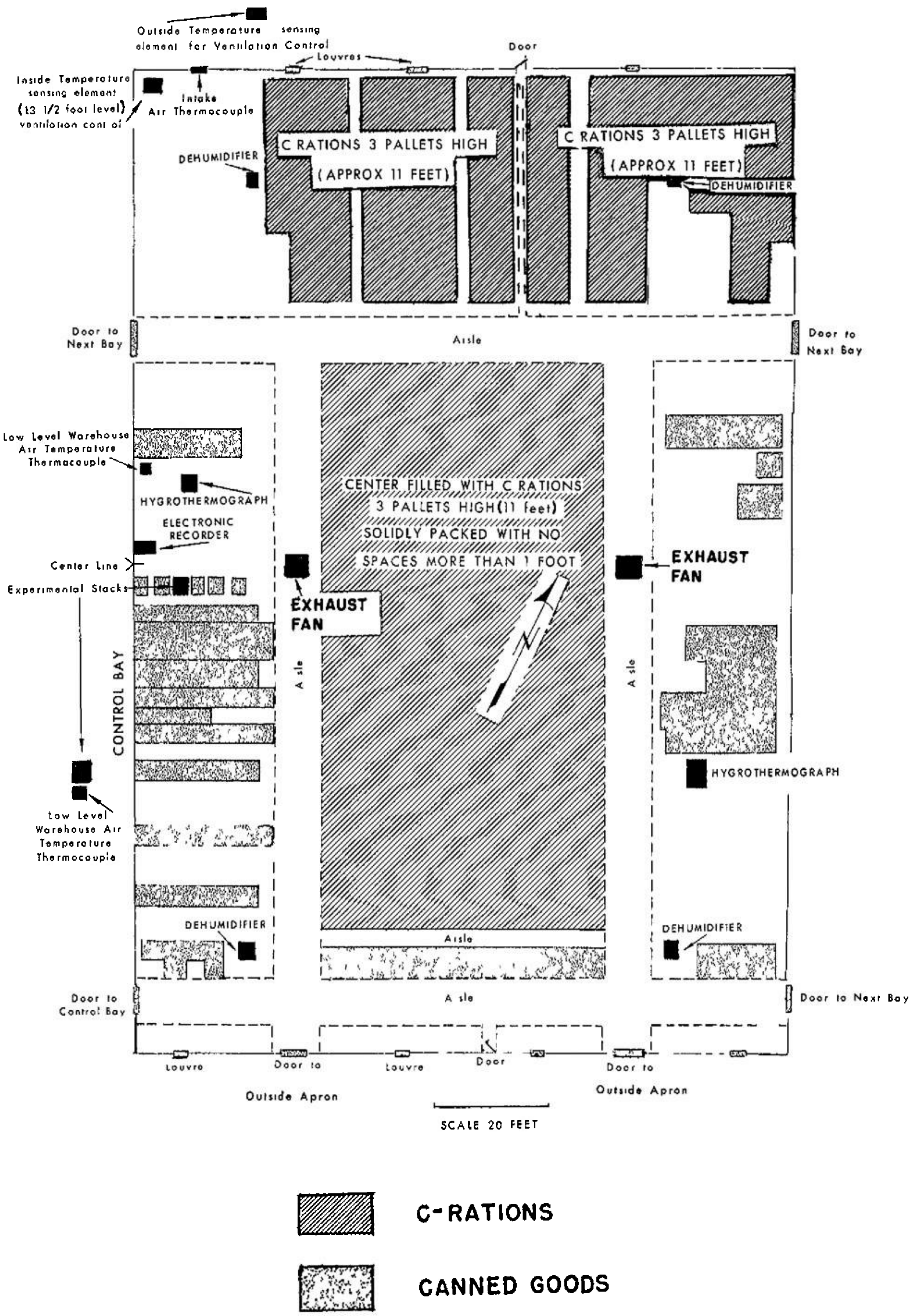


Figure 10 Floor plan of ventilated bay.

shutters with inclined metal vanes are outside the louvers The latter open automatically when the fans are operating. At the beginning of the study the intake of air was poor The north side louvers were blocked by pallets stacked within one foot, and the outer shutters prevented the inner louvers on both north and south sides from fully opening, with a very low resultant inflow of air. However, this was modified 5 April 1957, by removal of the outer shutters on the south side intakes. Mean intake air flow increased two to three times, as measured with a wind vane anemometer This improvement could not be achieved on the north side. Here, the outer protective shutters could not be removed, since there was no overhanging roof to protect from driving rain, as there was on the loading platform side. On this side of the warehouse, operation of the exhaust fans did not automatically open the intake louvers, as it did on the south side.

From each bay, two large loading doors lead to the loading platform, and two to each adjoining bay These are closed by metal firedoors at the close of the working day.

Bays A and B of this warehouse were used in this study Bay A was not altered in any way, and served as the control bay. The western third of this bay contained a vacuum dehydration apparatus, which was not used at all during the night and only occasionally during the day In its center section, Bay A was loaded with stacked

bags of wheat flour, and next to the common wall of Bay A and B, boxes of spaghetti in crates were piled four pallets high

Bay B was modified in the following manner The underside of the roof, both in the monitor and side areas, and the windows of the monitor, were sheeted with aluminum foil laminated on both sides of Kraft paper and stapled to wood furring attached immediately below the steel purlins The sheeting was thus about eight inches from the under surface of the roof. This was installed to reflect radiant heat from the roof during the daytime hours.

The two exhaust fans mentioned above were each of one horsepower and capable of moving 10,200 cubic feet of air per minute, although the actual flow was less due to intake restrictions, as will be discussed in relation to adequacy of ventilation procedures(p. 49).

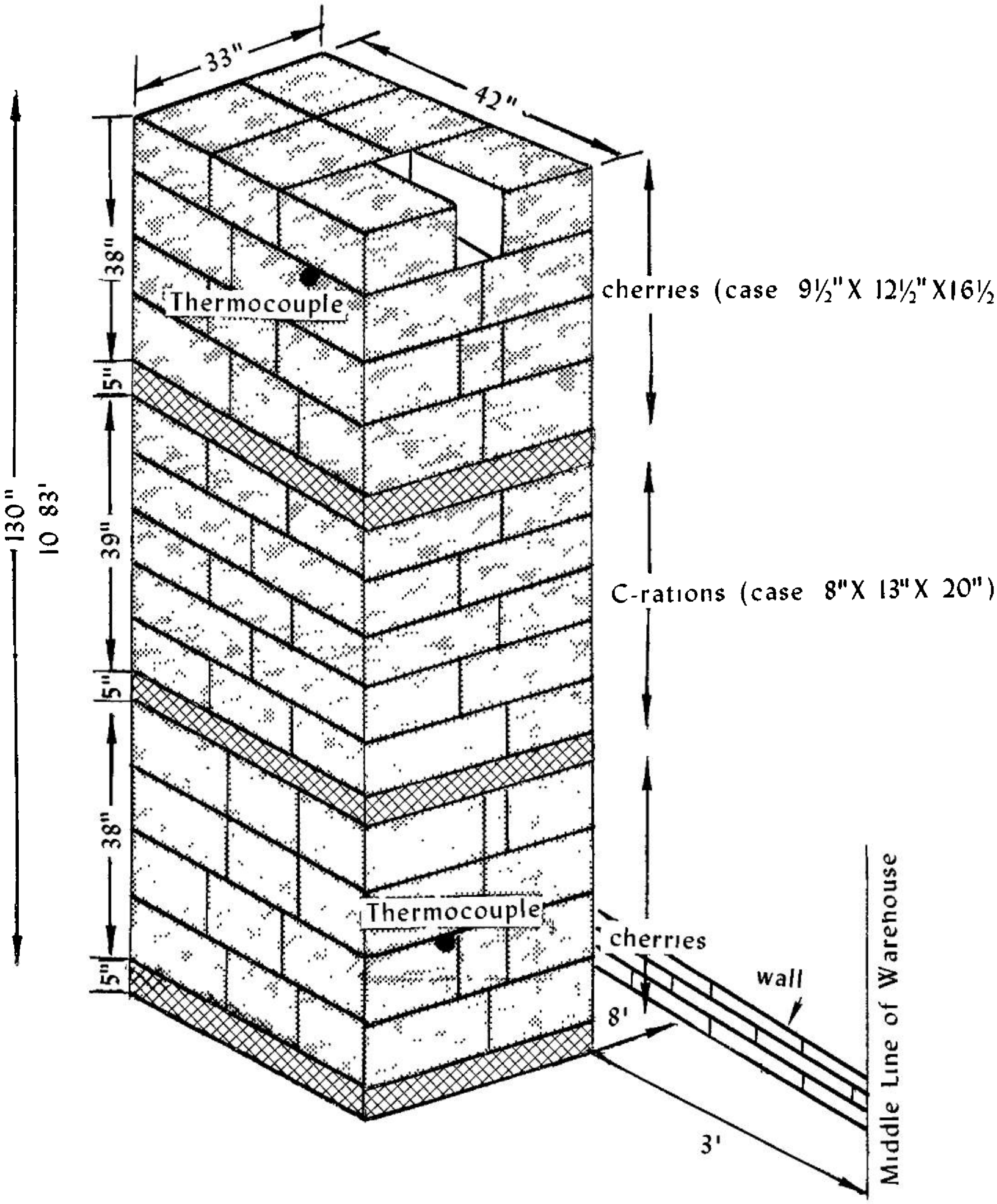
A fan control system containing a differential dewpoint indicating controller, a time clock control, and a differential thermostat controller in series, was installed in the northwest corner of the study bay. The temperature controller was a pressure device, the heating of the sensing element causing expansion of gas in a contained system. The outer element was located in a white, meteorological-type shelter at 4 1/2 feet height, 13 feet north of the brick outer wall. The inner element was at 13 1/2 feet elevation above the floor of the warehouse, two feet from the north and west walls of the bay in the corner It was originally

planned that during the automatic ventilation period, the controller would actuate the fans if the outside temperature were 4 F° below the inside, if the outside dewpoint were lower than that inside, and if the time were between 2000 and 0500 In actual practice, however, only the temperature and time controls were used, the latter being set for 1700 to 0730

Four self-contained refrigerated dehumidifiers (Fig 12), located as in Fig 10 and capable of maintaining relative humidity at 55% under normal conditions, were installed in Bay B to cope with any abnormal increase in humidity which might result from the forced ventilation

2 Characteristics of the Load

Approximately 40 carloads (85,000 cases or 2300 tons) of food (Ration, Individual, Combat - C) were stacked in the warehouse as shown in Fig 10. They were stacked three pallets high with the usual five inch air space within the pallet and between stacks (Fig. 11), and occupied a floor area of approximately 10,100 feet, out of a total floor space of 21,600 sq. ft. Total volume of the bay was 440,000 cu. ft., of which 110,000 or 25% was occupied by the load, pallets, and spaces between cartons This load was made up of items in so-called "dead stock", which were to move little during the course of the study, and thus keep entry to the bay at a minimum. The warehouse staff was instructed to keep the doors to Bay B closed at all times, except when entry to the Bay was essential



High level warehouse air thermocouple (vent. bay)
27" above top of stack

High level warehouse air thermocouple (control bay)
30" above top of stack

Figure 11 Side view of experimental stack.

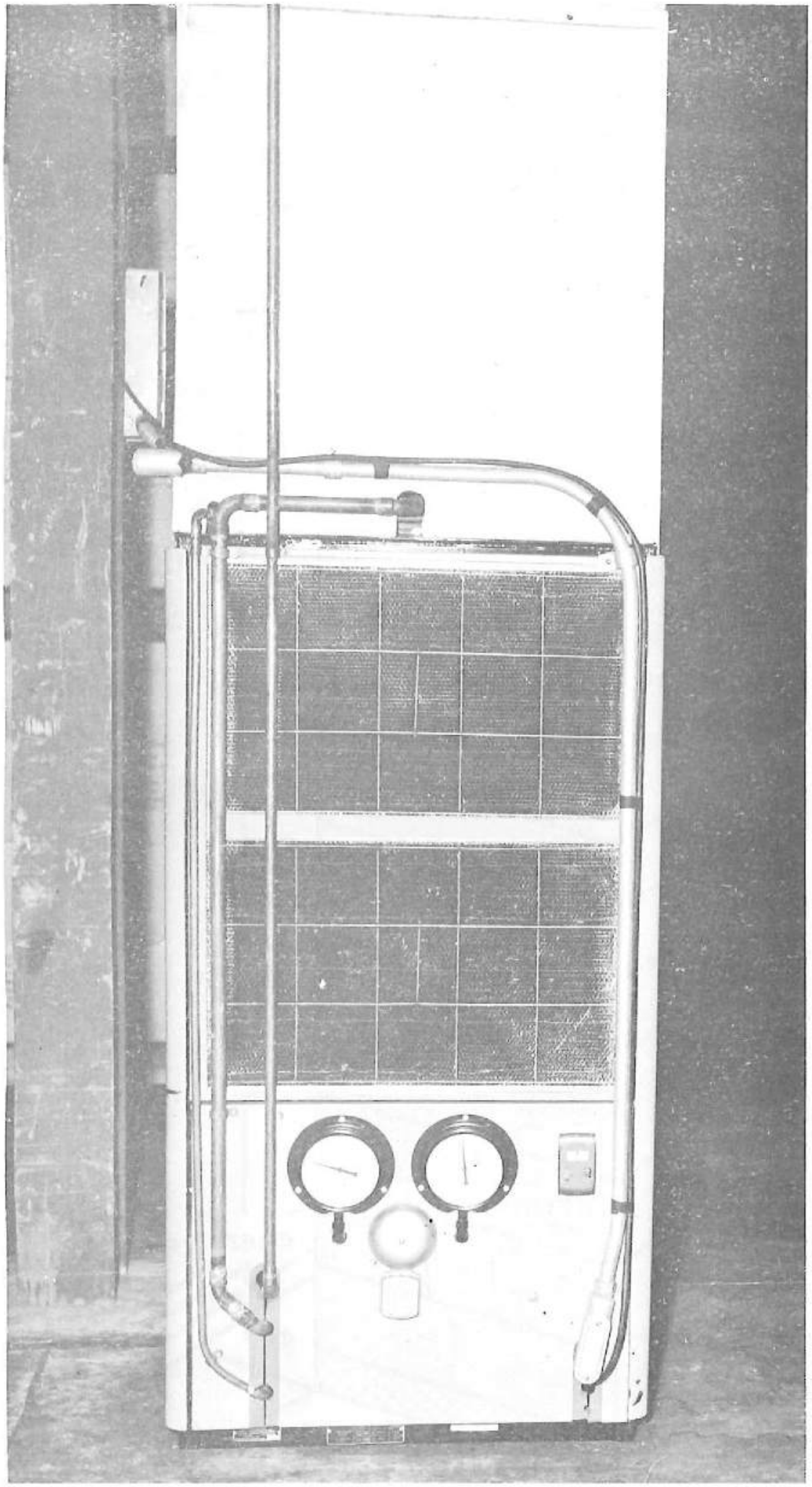


Figure 12. Dehumidifier.

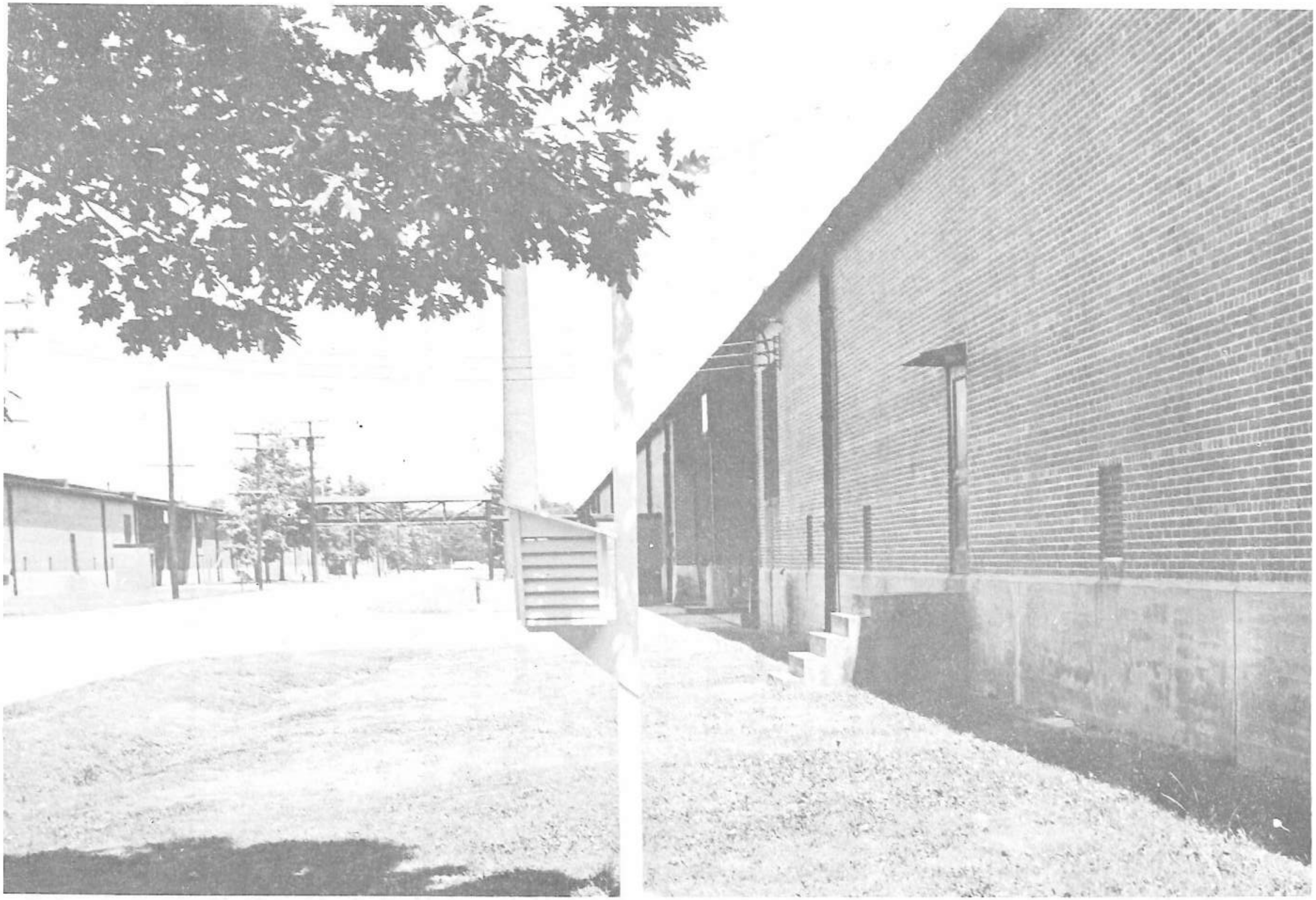


Figure 13. North side of warehouse showing ventilation louvres and weather shelter.

A small area along the west side of the section, and in the middle, was left open for the experimental samples and the recording instruments Pallets ("flats") of experimental food cartons were stacked in this area threehigh, as elsewhere in the warehouse The actual stack whose temperatures were studied (Figs 11 and 14) was initially placed near the west wall of the warehouse 3 feet south of the centerline and contained cherries in the top and bottom pallets and Combat "C" Rations in the middle pallet An identical stack was placed in the Control Bay opposite this stack, but 38 feet south of the centerline Other pallets in the experimental section contained cartons of cherries, peaches, peas, and beets (in bright metal cans) together with Combat (Individual) and 5-in-1 rations. The study stacks were moved to a position 8 ft from the wall in April 1957, and they contained only canned peas for the remainder of the study.

It was originally planned that cartons of food would be withdrawn from these stores at intervals and tested for loss of essential nutrients, but the low temperature differential between experimental and control bays which was achieved during the first year of the study (1956) lead to the cancellation of this plan, although the subsequent year gave markedly larger differentials

3 Measurement Procedures

In both experimental (ventilated) and control bays, temperatures were measured at two points within the air in the cartons of the top and bottom pallet and two points within the

Figure 14. Experimental stack.

air of the warehouse next to the stack at approximately 13 ft and 34 in elevations (Table III and Fig. 11). The high level air temperature thermocouples were located two ft over the top pallet of the stacks and eight to ten ft. from the wall The air temperature thermocouple in the Control Bay was at 15 ft. elevation.

The carton air thermocouples (Figs. 11 and 14) were originally located in the air at the top of a carton of the first stack next to the wall and only one carton away from the wall itself. This was modified 8 April 1957, so that the thermocouples were in cartons of the third pallet from the wall in both bays, at similar heights to the original ones, but now about eight to ten ft. from the wall (Fig. 11). The study cartons in the experimental stacks originally contained 24 cans of cherries, but after 8 April 1957, when the stacks were changed, they contained 24 cans of peas similar to the rest of the stack.

Temperatures were measured with copper constantan thermocouples from 2 April to 12 June 1956 on a 6-point Bristol electronic potentiometric recorder printing 2 points per minute with a chart speed of 2 in. per hour On 12 June 1956, a 12-point Brown Electronik Recorder (potentiometric) was substituted with a print speed of 2 points per minute and an interrupter mechanism which permitted operation for two seven minute periods per hour, separated by 23 minutes of non-operation. At the same time a weather shelter was

Table III. Temperature and Humidity Measurement Positions[a]

Label on Graphs and Tables	Bay	Details of Location
Bottom Carton Air Temperature Study Stack	Vent.[c] Cont.[d]	Top of second carton from bottom in bottom flat - 24 in. above floor - canned peas
Low Level Warehouse Air Temp Next to Study Stack[e]	Vent. Cont.	Air 34 in. above floor 20 ft. northwest of study stack
Intake Air Temperature Low Level[e]	Vent	Air 5 in. inside of northwest air intake louver - 3 ft. above floor
Low Level Warehouse Air Temp. Hygrothermograph Next to Study Stack[b]	Vent. Cont.	Air 42 in. above floor 20 ft. north of study stack Air 24 in. above floor next to study stack
Low Level Warehouse Temp. Hygrothermograph in "C" Bay[f]	"C"	Air 34 in. above floor in bay east of ventilated bay, near door to ventilated bay
Warehouse Floor Surface Temperature	Vent	Floor surface 10 ft north-west of study stack
Top Carton Air Temperature Study Stack	Vent.[c] Cont.[d]	Top of second carton from top in top flat - 10 ft. above floor - canned peas
High Level Warehouse Air Temperature - Next to Study Stack	Vent. Cont.	Air 13 ft. above floor over study stack Air 15 ft above floor 10 ft. south of center line of warehouse and 10 ft. from wall between bays
Exhaust Air Temperature	Vent.	Air 8 in. below louvers of exhaust ventilators - below warehouse roof level

(cont'd)

Table III (cont'd)

Label on Graphs and Tables	Bay	Details of Location
Outside Air Temperature Richmond Depot[e]	Outside Warehouse	Air in standard U.S.W.B. instrument shelter - 5 ft. above ground and 20 ft. northwest of control bay
U.S.W.B. Air Temperature - Byrd Field	Outside Warehouse	Same as above, but located at Byrd Field, Richmond

[a]From 2 April 1956 until 15 May 1958, except as noted in these footnotes or in Table IV

[b]First installed 27 June 1956. Relative humidities were also measured at these positions Means, frequencies, and standard deviations of these humidity data as well as of the dewpoints computed from them are also shown in the tables and graphs.

[c]Study stack in ventilated bay was 3 ft. south of center line of warehouse and flush against west wall from beginning of study, 2 April 1956, to 7 April 1957. On this date it was moved to the third stack from the wall, 8 ft. from the wall. Carton air thermocouples were located in cartons containing 24 No. 2 1/2 bright metal cans of sweet cherries in the first period and in comparable positions in cartons containing similar cans of peas in the second period.

[d]Study stack in control bay was 38 ft. south of center line of warehouse and flush against the wall between bays from 2 April 1956 to 7 April 1957. On this date it was moved to the third stack from the wall, 8 ft away from the wall Thermocouples were in cartons containing canned sweet cherries in the first period and peas in the second period.

[e]Installed 12 June 1956.

[f]See Table IV. First installed in "c" bay 8 April 1957.

Table IV. Changes in Temperature and Humidity Measurement Positions

Date	Label On Graphs and Tables	Bay	Details of Location
12 June to 24 Aug 1956[a]	Exhaust Air Temperature	Vent	Air 3 in. above louvers in exhaust ventilators - above warehouse roof level
12 June to 24 Aug. 1956[a]	Roof Monitor Air Temp.	Vent.	In contact with exhaust fan motor in roof ventilator housing - one foot above louvers and above warehouse roof level
2 April to 27 June 1956	Low Level Warehouse Air Temperature - Hygrothermograph in Northeast Corner of Bay	Vent.	20 ft from north and east walls of ventilated bay - 2 ft. from floor
2 April to 27 June 1956	Low Level Warehouse Air Temperature - Hygrothermograph in Southwest Corner of Bay	Vent.	20 ft. from south and west walls of ventilated bay - 2 ft from floor
2 April 1956 to 8 April 1957	Low Level Warehouse Air Temperature - Hygrothermograph in Southeast Corner of Bay	Vent.	15 ft from east and 50 ft. from south wall of ventilated bay - 2 ft from floor

[a]First installed 12 June 1956.

installed (Fig. 15). It was therefore possible to add thermocouples placed in the outside air shelter, in the air just inside an intake louver, in the air of the exhaust opening just below the automatic louver, and on the surface of the floor of the warehouse next to the Brown Recorder. A list of thermocouple positions is given below (Tables III and IV) together with the position of three mechanically-actuated hygrothermographs used to record temperature and humidity. For more ready identification, these positions will be capitalized when referred to in text, tables, or figures below

On 12 June 1956 a standard small U. S. Weather Bureau Instrument Shelter (Fig 15) was positioned on the grassed area 25 ft. west and 15 ft north of the northwest corner of Warehouse 32 It contained maximum and minimum thermometers and a thermocouple to measure ambient air temperature. Maximum and minimum temperatures were manually recorded every day at this position. This provided a sufficiently accurate daily check upon the temperatures recorded by the thermocouples, since the ambient air thermocouple was located two inches from the maximum and minimum thermometers The correction thus obtained was applied in the data reduction process. In addition, the Brown Recorder was manually standardized at ice water and room temperatures when the correction became excessive

Figure 15. Instrument shelter.

Furthermore, a weekly reading of low level warehouse air temperature and humidity was performed manually to provide a check on the hygrothermographs. The proximity of the Low Level Warehouse Air position on the Brown Recorder to the similar position of the hygrothermographs and the manual reading mentioned above, provided an additional check on the data

It is felt that measurement errors amounted to no more than $\pm$ 1 F° for most of the data. Since much of the study concerns a comparison between temperatures in two bays, which were recorded on one instrument, the errors of recording are insignificant in the comparative part of the study Errors in data reduction will be discussed below

4. Data Reduction, Processing and Analysis

a. Data Reduction

The data available for reduction consisted of approximately 3600 feet of strip chart from the Bristol and Brown Recorders and some 2000 circular charts from the recording hygrothermographs Temperature and relative humidity data for 18 positions were read from the charts for every hour by means of a Contact Telereader, Teleducer, Program Unit[1], Electric Typewriter, and Keypunch.

[1]Telecomputing Corporation, North Hollywood, Cal., was the supplier, although such equipment is now available from several firms.

All data were reduced on an hourly basis, referred to Eastern Standard Time Because the study was planned around nighttime ventilation, the study day began at 0900, which was designated hour 01. Hour 16 of the study was 0000 of the next calendar day, and hour 24 of the study day was 0800 of the next calendar day.

b. Data Processing by Computer

The range of the data was sufficiently small so that the slight non-linearity of the electronic recorder charts did not require a progressive correction. A standard composite correction corresponding to the baseline chosen for data reduction and the temperature correction for the day was added by a computer (G. E. 225) to each temperature reading, the resulting corrected temperature being rounded without bias to whole degrees.

For each temperature and relative humidity derived from the hygrothermograph readings, a dewpoint was machine-computed, using standard conversion tables which had been transferred to a punch-card deck For each hour, the corrected temperatures, calculated dewpoints, and the U. S. Weather Bureau dry bulb temperature and dewpoint from Byrd Field, Richmond, (13), were entered on a master card which served as the permanent record and basis for further machine computations

Frequent checks showed that errors in data reduction for individual readings were no more than $\pm$ 1 F^{o}. The sensitivity and

reproducibility of the data reduction system were much greater than the precision possible for human operators in placing the cross hair, even when using a hand lens Since the results were expressed as means and frequencies developed usually from a minimum of 700 observations, such small errors had only a minimal effect.

c. Data Analysis

A mean, standard deviation, and percent frequency distribution were computed for each calendar month for each of the 23 parameters available. In addition, a percent frequency distribution of hours of actual ventilation for each two degree class of difference between inside and outside temperature was computed. A similar frequency distribution based on difference between outside and inside temperature was computed for all hours when three conditions considered necessary for most beneficial ventilation were met: (1) outside temperature less than inside temperature, (2) outside dewpoint less than inside dewpoint, and (3) outside temperature greater than inside dewpoint. This latter appears in the graphs and tables as "Predicted Satisfactory Ventilation".

Finally, the relationship of monthly mean top carton air temperature in the control bay to monthly mean outside temperature was computed as a regression equation.

C. Limitations of the Study

1 Climatological Representativeness of the Place and Time of Study

Table V shows, for representative climatic variables, a comparison of the twenty-nine year normals for the hottest month and the entire year as compared with similar means for 1956 and 1957, which included the majority of the study.

The table shows that the research period was to a great extent representative of climatic normals, and indeed, was somewhat hotter in both the hottest month, July, and the entire year, than the normal Since mean warehouse air temperatures are very closely correlated with mean outside air temperatures (16), the years of the study would appear satisfactory with regard to heat stress limits

Figs 5 and 6, maps of effective mean yearly and effective mean hottest month temperatures for food storage in Army warehouses, indicate that Richmond is representative of storage conditions in the southern midcontinent However, in general the most extreme conditions for the hottest month would prevail in the Southwest, for example, in the Texas warehouses, predicted food degradation rates, based on 5 F$^{\circ}$ higher monthly mean warehouse temperature and a doubling of rate for a temperature increase of 18 F$^{\circ}$, would be at least 20% greater than those at Richmond

Table V. Climatic Comparisons

TEMPERATURE (°F)	July 1956	July 1957	July[a] Normals	Year 1956	Year 1957	Year[a] Normals
Absolute maximum	99	100	104	99	100	104
Absolute minimum	57	55	51	16	0	-12
Mean maximum	88 0	90.3	87.8	68.8	68.9	68.6
Mean minimum	67.5	66.5	67.2	47 8	48 4	46.7
Mean	77 8	78.4	77.5	58.3	58.7	57.7
RELATIVE HUMIDITY (%)						
Mean 0700	84	78	84	81	84	83
Mean 1300	58	43	55	55	56	53
DEWPOINT (°F)						
Mean 0700	68	63	Missing	50.2	50.3	Missing
Mean 1300	68	61	Missing	50.5	50.1	Missing
Mean daily	67.8	62.8	67.3[b]	50 6	50 9	50 7[b]
WINDSPEED (mph)						
Mean	7.2	7.1	6.9	8.3	7.7	7.7

[a]Temperature, relative humidity, dewpoint, and windspeed data were obtained from U.S.W.B. (14) are based on a twenty-nine year record from 1921-1950 Absolute maxima and minima are extremes of the period of record.

[b]Data from Reference 15

2 Accuracy of Measurement

Sufficiently accurate measurements were ensured by the daily temperature check on the ambient temperature thermocouple, the weekly temperature and humidity check on the hygrothermographs and the warehouse floor level air temperature thermocouple, the close agreement of individual and mean values for the same position recorded separately by hygrothermograph and thermocouple, and, finally, by the close agreement of ambient temperature means and frequencies measured by thermocouple at Richmond Depot with those derived from U.S.W.B. values by Byrd Field (13) (Figs. 22-50 and Tables VI-LXXVII).

In addition, since the temperatures used in comparison of ventilated and control warehouses were measured on the same recorder, it would appear that errors in comparative measurements are even less significant.

3 Adequacy of Ventilation Procedures

It was noted above that 5 to 15 air changes per hour are recommended for efficient night-time ventilation in warehouses The study bay had only 2 one-horsepower exhaust fans, and it was found by anemometer measurements that the intake system (page 30, above) was inadequate for the exhaust potential, even after removal of the outer shutters on the intake louvers. It was calculated that a maximum of only 3 air changes per hour was achieved during the most effective night-time ventilation periods. This

is well below the recommended amount. Fig. 19 shows that even with full ventilation the intake temperature was four to six degrees below exhaust air temperature between 0100 and 0600 of July 23, the morning hours following the hottest day of 1957.[1]

Furthermore, our data showed that during 38% of hours of actual ventilation the inside air temperature at 15 feet in the ventilated bay was nine degrees or more above the outside air temperature. It is plain that during the 21 months during which forced ventilation was occurring 10-15 hours per night between 1700 and 0800, there yet remained a very great reserve of potential cooling power, which a more powerful exhaust fan and adequate intake system could have exploited. The ventilation system was thus inadequate for demonstrating the potential cooling available, the amount of which can only be judged by extrapolation from the cooling shown in the results discussed below.

Results

Since the study was aimed at the measurement of temperatures occurring in the air of cartons of food in a typical Army warehouse

[1]Note that these appear as hours 17-22 of the study day July 22, as explained on page 45

under various conditions of ventilation and insulation, specific analysis of the observed data has been made only for the Top Carton Air Temperature[1] in the ventilated and the control Bays, the most critical position for food For these positions, the following items have been evaluated:

1 Temperatures cycles on the hottest day of each of the years 1956 and 1957 (Tables LXXVIII and LXXIX and Figs 16-21)

2. Means, standard deviations, and frequency distributions of hourly temperatures, by individual months of each year and for the whole year (Tables VI-LXXVII, Figs 22-50).

3. Linear regression equation of monthly mean Inside (Top Carton Air) Temperature on monthly mean Outside (Ambient) Air Temperature (Fig 51)

4. Prediction of actual and effective mean warehouse temperatures with relation to sterile food degradation (Tables LXXX, LXXXI and LXXXII)

5. Frequency of ventilation hours, by classes of temperature differential between inside and outside air (Figs 22-50)

6 Effect of reflective insulation (Fig. 53).

7. Effect of ventilation (Fig 53)

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[1]Names of recording positions are capitalized throughout the report.

For the other positions where temperature and humidity measurements were made (shown in Table III), Tables VI-LXXVII and Figs. 16-50 show the analyzed data No further comment will be made concerning these data other than that incidental to the discussion of points 1-7, above These data reveal the entire warehouse environment on a month-by-month basis, and are included to accommodate those readers who might find them useful.

A. Temperature Cycles on Hottest Days

To show absolute extremes for the research period, the temperature cycles for 2 July 1956 and 22 July 1957, are shown in Figs. 16-21. These days showed the highest Top Carton Air temperatures for the years studied.

The data for 2 July 1956, show the effect of the reflective ceiling insulation which had been in place for one year. Ventilation had not commenced. The weather for this day was dominated by a typical southwesterly flow of warm, moist, maritime tropical air, with occasional cumulus congestus clouds, but generally fair conditions.

The effect of position of temperature measurement is shown by the following maximum and minimum temperatures (Table LXXVIII).

The daily range of temperature differs greatly at the various positions. Thus, although the means of warehouse air and carton air at the same height are quite close, the maxima and

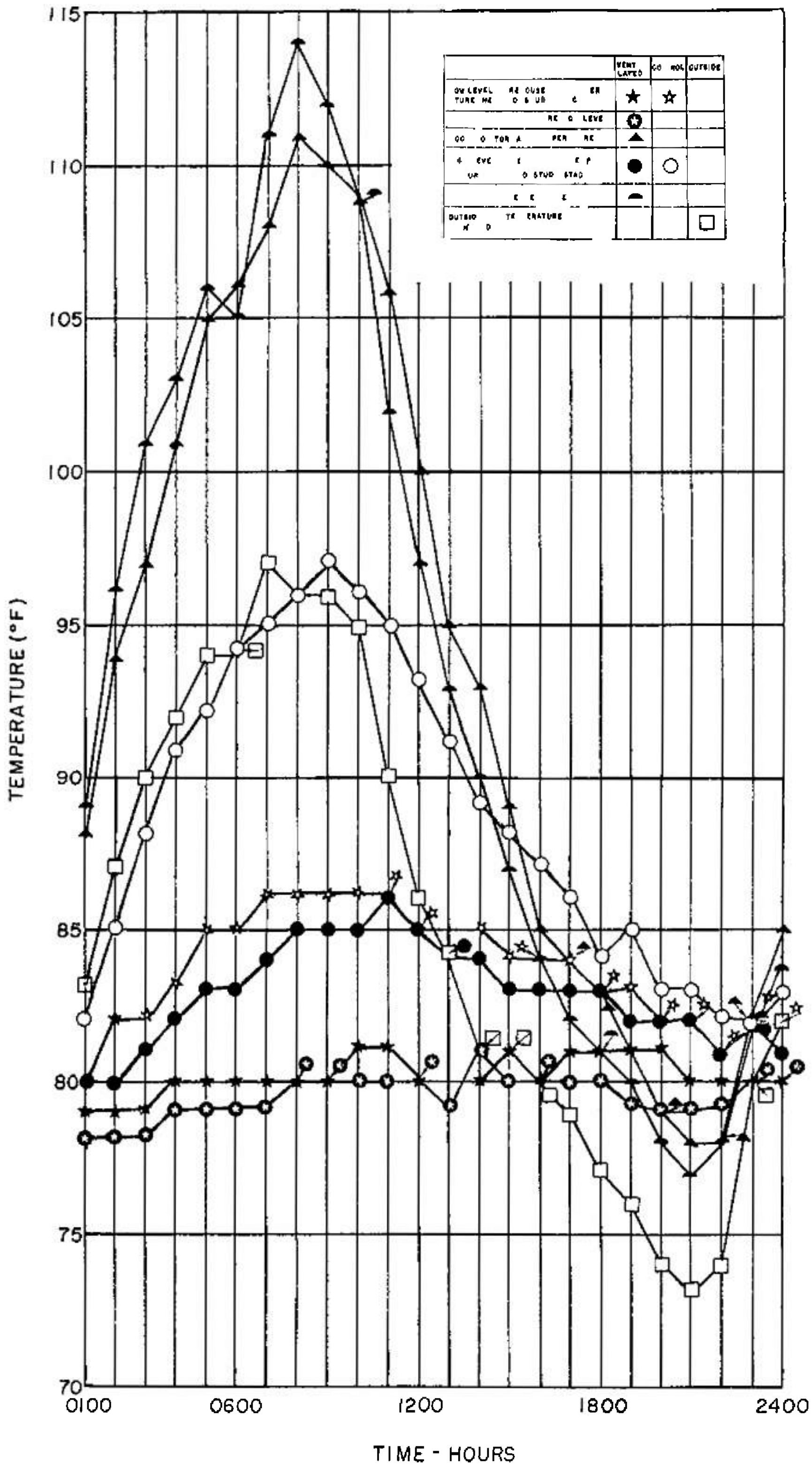

Figure 16 Warehouse air temperatures for hottest day, 1956.

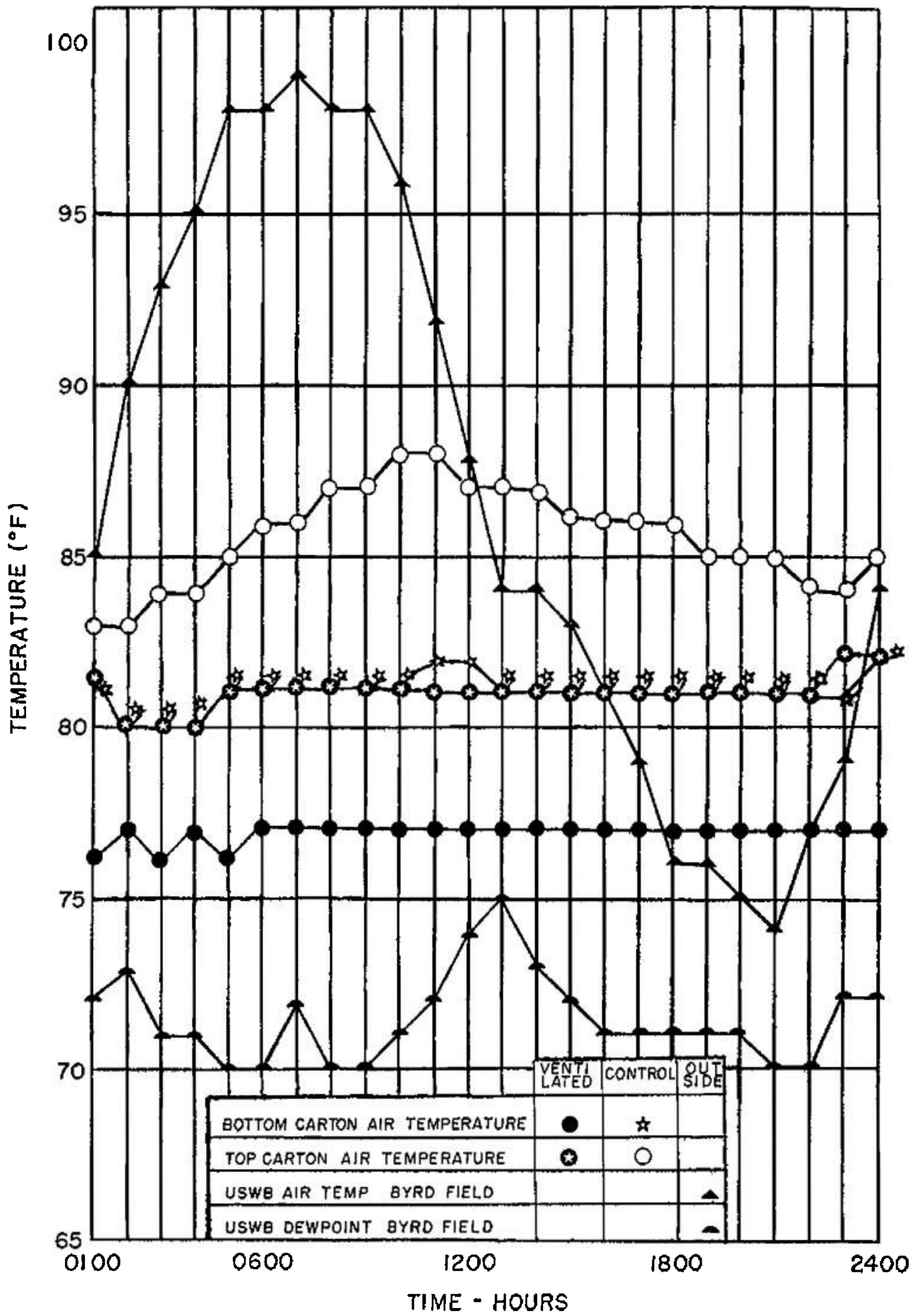

Figure 17 Carton air temperatures for hottest day, 1956.

Table LXXVIII. Hottest Day Temperatures - 2 July 1956

Position	Temperature[a]							
	Maximum		Minimum		Mean[b]		Ranges	
	C	V	C	V	C	V	C	V
Exhaust Air[c]		114		77		96		37
High Level Warehouse Air	97	86	82	80	90	83	15	6
Top Carton Air	88	82	83	80	86	81	5	2
Low Level Warehouse Air	86	81	80	79	83	80	6	2
Bottom Carton Air	82	77	80	76	81	76	2	1
Outside Air		97		73		85		24

[a] V - Ventilated, C - Control Bays

[b] Derived from (Max - Min)/2

[c] As defined in Table IV.

hence, the ranges, differ widely. This is a characteristic feature of temperature cycles in enclosed storage spaces which are subjected to daily cycles of radiation and ambient temperature The means in free air, carton air, and food temperatures at the same height, and indeed, at different heights and for different degrees of packaging protection, are often very close It is the standard deviations and the maxima of daily, weekly, and monthly temperature frequency distributions that show much greater dispersion and reflect the differing exposures. Thus, the daily pulse of heat income and outgo produces a smaller effect at lesser heights and in more protected situations.

For example, the hygrothermograph data of Fig. 18 show that there is little difference in temperature regime between various areas of a given bay. However, Table LXXVIII indicates there is a difference of 4 to 6 F° between Top Carton and Bottom Carton Air Temperature maxima, and a greatly reduced range at the lower level.

In general, however, the daily range of carton air temperatures is less than 5 F° even at the most critical Top Carton position.

The reflective insulation obviously reduces the maximum daytime temperature in both the free air and carton air of the

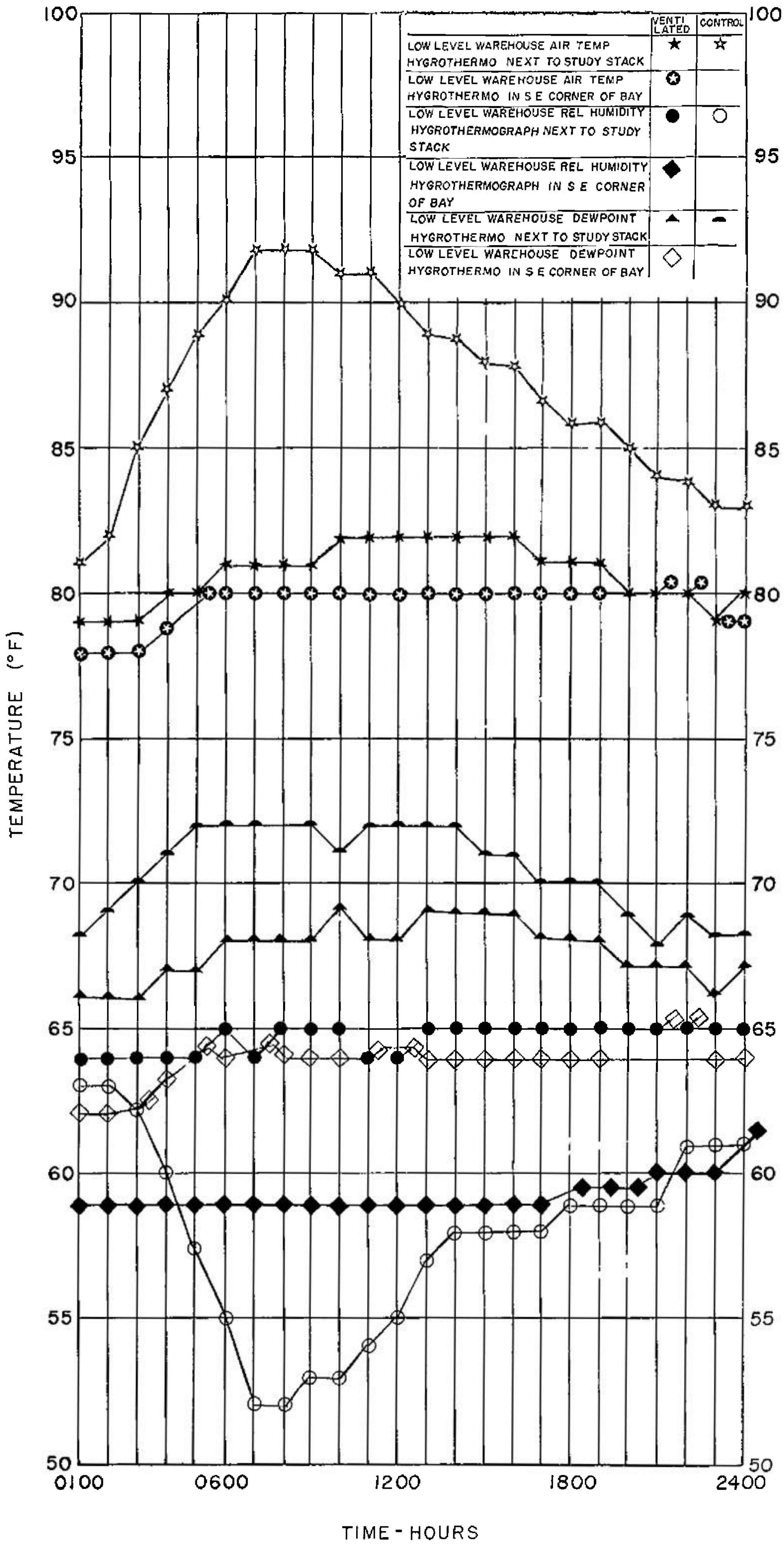

Figure 18 Hygrothermograph observations for hottest day, 1956

ventilated bay. Minimum temperatures are but little affected, and, indeed, the rate of cooling of the uninsulated bay is much greater than its insulated counterpart, as would be expected, since outgoing radiation from the roof at night is also reduced. Mean temperature is correspondingly less reduced by the insulation than maximum temperature

On 22 July 1957, weather conditions were very similar to those for 2 July 1956, except that at approximately 2100, Hour 13 on Fig. 19, a thundershower occurred which caused a temporary sharp drop of outside air temperature, and a continuous cloud cover thereafter markedly reduced cooling rates for the balance of the night. Thus, although automatically actuated ventilation had been in nightly operation since 16 April 1957, Top Carton Air temperatures were not reduced in the Ventilated Bay on this night, even after Hour 12 (2000) when fans went on However, Top Carton Air temperatures in the Control Bay remained high also, without the 4 F^{o} drop which occurred on 2 July 1956 The data follow (Table LXXIX)

The similarity of means but the differing ranges at various positions noted above for 2 July 1956 are also evident on 22 July 1957. The position labeled Exhaust Air Temperature gives a good idea of the spread of air temperatures throughout the warehouse, since it is at a height of about 27 ft above the floor at the

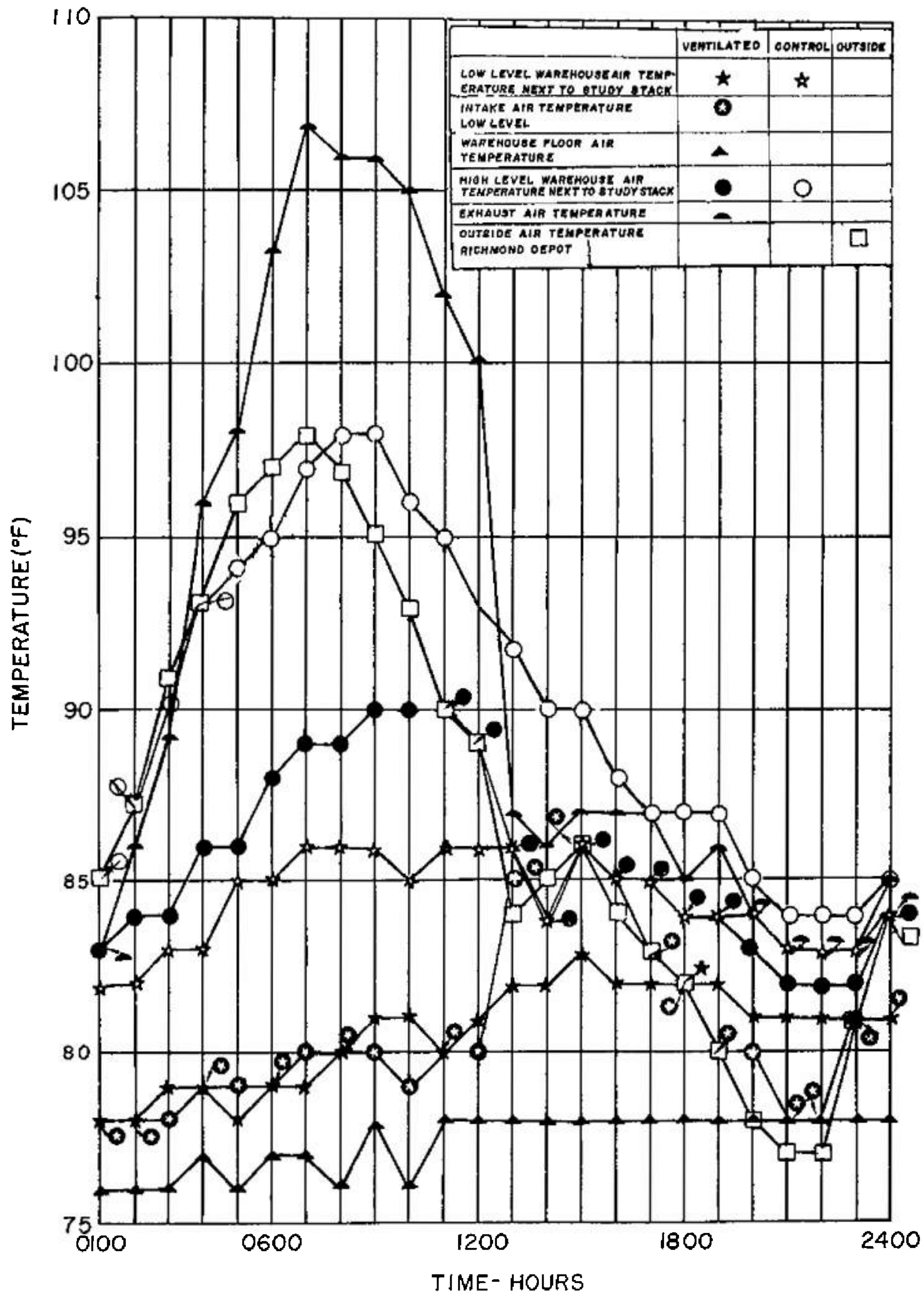

Figure 19 Warehouse air temperatures for hottest day, 1957

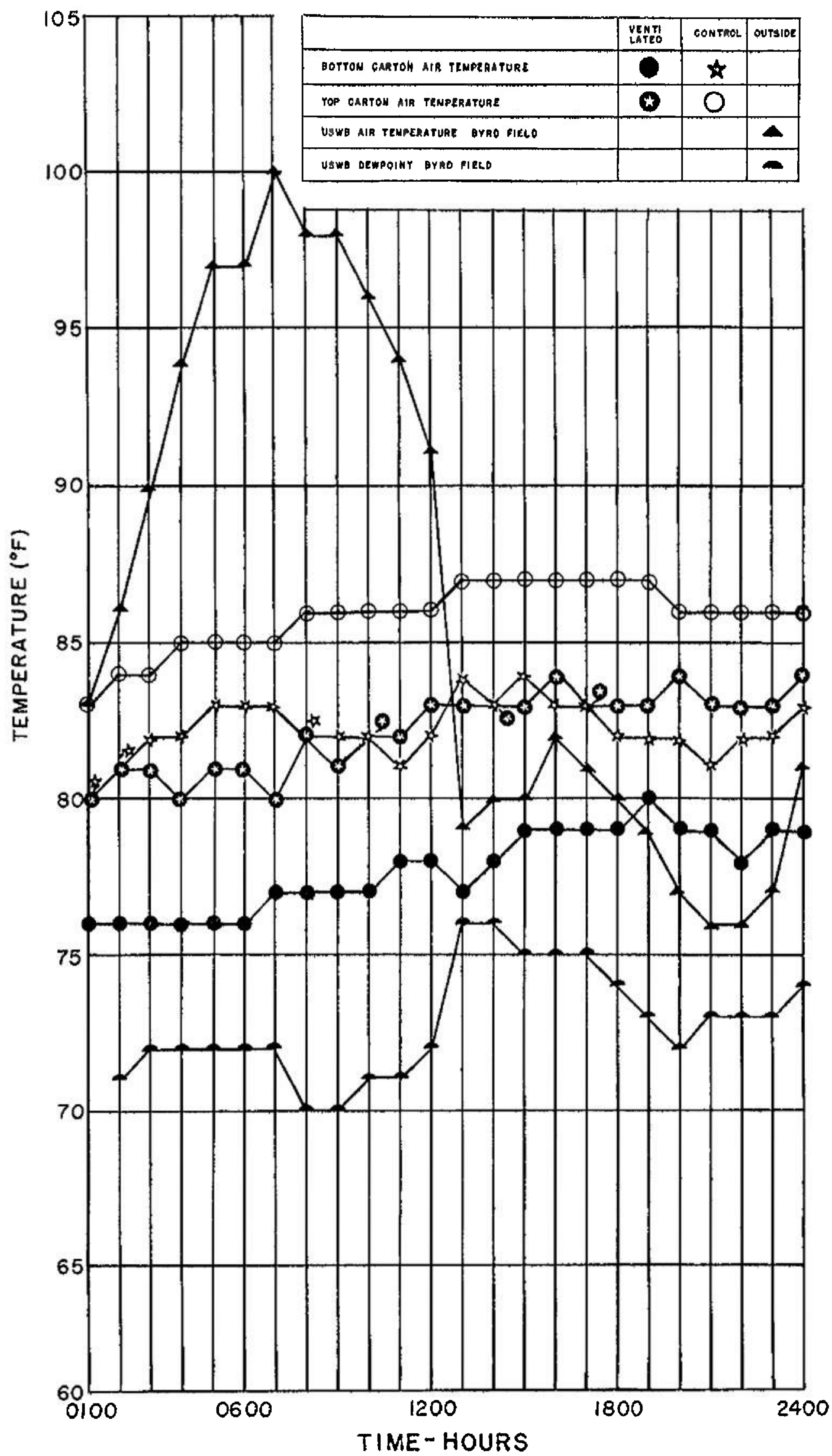

Figure 20 Carton air temperatures for hottest day, 1957.

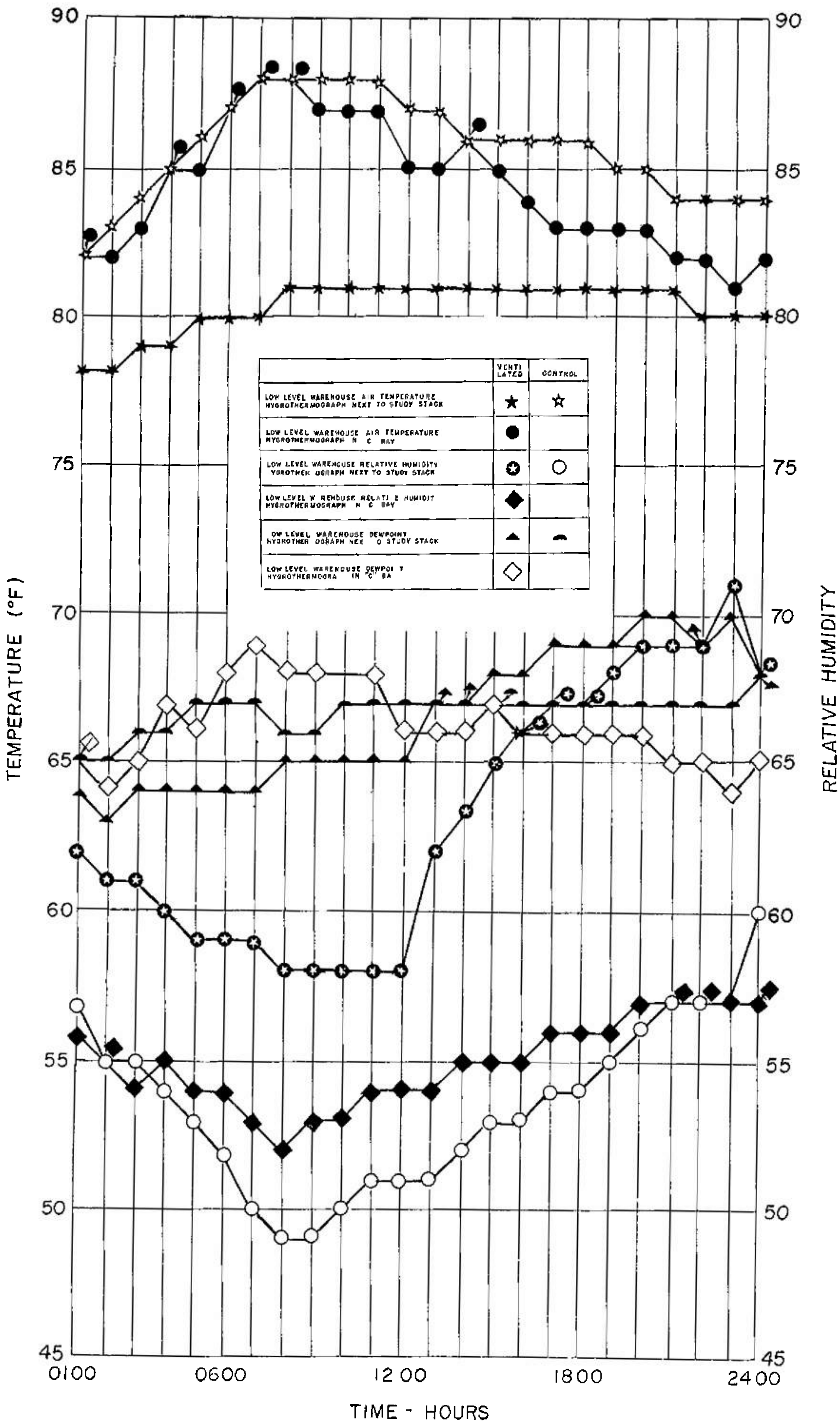

Figure 21. Hygrothermograph observations for hottest day, 1957

Table LXXIX. Hottest Day Temperatures - 22 July 1957

Position	Temperature							
	Maximum		Minimum		Mean		Range	
	C	V	C	V	C	V	C	V
Exhaust Air[a]		107		83		95		24
High Level Warehouse Air	98	90	84	82	91	86	14	8
Top Carton Air	87	84	83	80	85	82	4	4
Low Level Warehouse Air	86	83	82	78	84	80	4	5
Bottom Carton Air	83	80	80	76	82	78	3	4
Outside Air	98		77		88		21	

[a]As defined in Table III. Note that this is now the temperature 8" below the louvers of the roof ventilators; therefore within the warehouse proper

top of the storage space. The minimum temperatures reveal that at the end of the night the warehouse becomes more nearly isothermal, in contrast to the great temperature gradient prevailing in the afternoon (1 F^{o} /foot).

The warmth of the night of 22-23 July 1957 prevented any very large cooling effect of the ventilation. However, Fig 19 shows that at Hour 12 (2000) Outside Air temperature had dropped below the High Level Warehouse Air temperature. This was the activating condition for the fans, providing the hour was between 1700 and 0730. Thus, they were automatically actuated, as is plain from the sharp rise in Intake Air temperature, the sharp drop in Exhaust Air and High Level Warehouse Air temperature, and the more moderate rises in Low Level Warehouse Air temperature and dewpoint The rises of the low level temperatures are due to the fact that on this night, although the upper levels of the warehouse are being cooled by the moderately cool outside air, the latter is warmer than the lower level warehouse air until approximately 0200, after which the entire warehouse experiences cooling

The High Level Warehouse Air maximum temperature on both of the hottest days in the Control Bay was the same as the Outside Air maximum. The Outside Air temperature minima were in general lower than minima in the Control bay

B. Means and Frequency Distributions of Hourly Temperature, Relative Humidities, and Dewpoints

For each month of the research period and for the total yearly periods, percentage frequency distributions of hourly observations of temperature, relative humidity and dewpoint, together with means, standard deviations, extremes, and a fraction showing ratio of number of actual to possible hourly observations are shown in Tables VI-LXXVII and Figs 22-50. Fig. 53 shows for each month the difference between Top Carton Air mean temperature in the Ventilated and Control Bays as a measure of the separate effects of insulation and ventilation.

The Top Carton Air monthly mean temperatures in the Control Bay are very closely correlated with monthly mean Outside Air Temperatures, as discussed below in Section III, c, and shown in Fig. 51. Since the slope of the regression line is about 45°, monthly mean Top Carton Air Temperature can be stated to be 5-10 F° above monthly mean Outside Air temperature in the normal range of temperatures throughout the year The persistence of this relationship is shown in Fig. 51 by the inclusion of three monthly mean temperature points and the computed regression line from the data observed in Top Level Warehouse Air in a different although identically constructed warehouse at Richmond in 1949 (4). The slope and intercept of the 1949 regression line

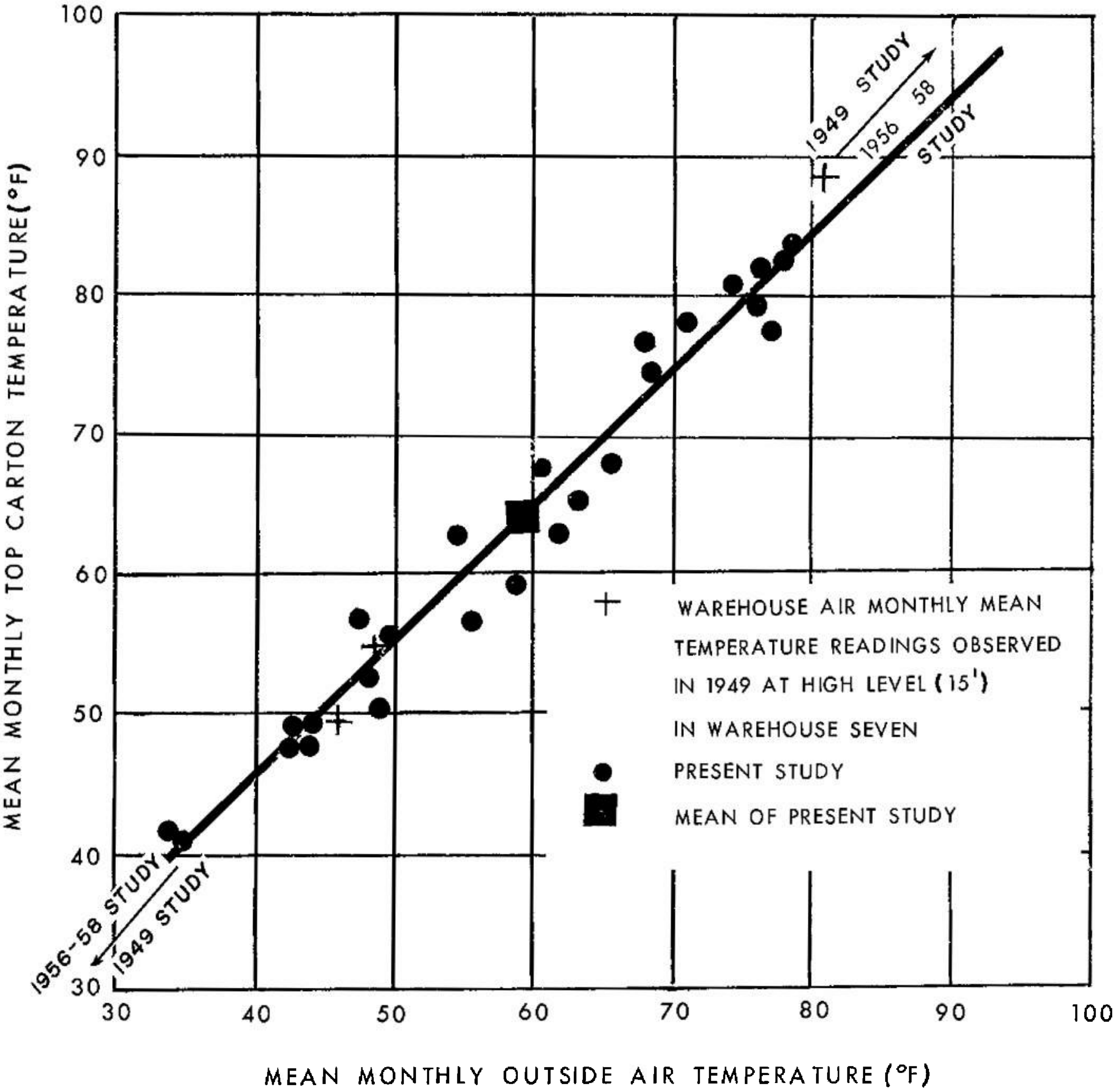

Figure 51. Relationship between mean monthly top carton air temperature in control bay and outside air temperature.

are nearly the same as those for these data, even though the 1949 data were taken seven years previously and were in Top Level Warehouse Air instead of Top Carton Air.

The variability of the Top Carton Air temperatures around the mean is shown in Tables VI-LXXVII and Figs. 22-50 For 21 out of 24 of the study months, the standard deviation of hourly temperatures at this position was 4 F^{o} or less. In 19 out of 24 cases the maximum temperature for the month at this position was given within two degrees by adding two standard deviations to the mean, the exceptions occurring in the cool months of early spring. Indeed, if the figure of 4 F^{o} be taken as the usual limit of standard deviation, the addition of twice this figure, or 8 F^{o} to the monthly mean will yield a temperature higher than the maximum in 19 out of 24 cases, the exceptions again occurring in the cool months of spring and fall.

The same consistency of the frequency distributions and correlation with outside mean temperature appears at other temperature measurement positions, as, for example, Top Level Warehouse air. The interested reader is referred to the data for the other positions in the warehouse shown in the tables and figures.

As was shown above for the hottest day temperatures, the mean temperatures at various positions within a given bay for a given month differ by less than 5 F^{o} , whereas the range of temperature is much more variable, depending on location, height, and degree of exposure or protection.

C. Regression of Monthly Mean Top Carton Air Temperature on Monthly Mean Outside Air Temperature

As noted in Section I-C above, the high level of correlation between long period means of inside and outside temperature found in the Yuma Boxcar and Yuma Dump Storage studies (7, 8) suggested that similar results would be obtained in correlation of Top Carton Air or Warehouse Air temperature with Outside Air temperature in warehouse studies.

As noted above in Section III-B, there was indeed a high correlation between monthly mean Top Carton Air and monthly mean Outside Air for the data of this study (Fig. 51).

The linear regression equation of monthly mean Top Carton Air temperature on monthly mean Outside Air Temperature for this study is as follows:

$$y = 6.8^{\circ} + 0.97x \pm 2.6^{\circ}$$

where y = Top Carton Air temperature

x = Outside Air temperature

correlation coefficient = 0 983 N = 23

confidence level = less than 1%

To develop this relationship further, linear regression equations were computed (16) from Sissenwine's data (4) for Top Level Warehouse Air mean monthly temperature and Outside Air mean monthly temperature at fifteen Army warehouses[1] (Fig. 54).

[1]Many of these warehouses have since been inactivated, but the group includes many types of warehouses so that high correlation would seem likely for most domestic and Army warehouses currently in use

Again, the two variables were found to be highly correlated, no coefficient being less than 0.98 where N was 12 (the twelve months of the test year, 1949-50). Average slope of the regression lines was 1.14, and average standard error of estimate 1.7 F°. At 70°F mean monthly Outside Air temperature, the estimated mean monthly Top Level Warehouse Air temperature ranges from 75-80°F, the family of regression lines being closely clustered (Fig. 54).

Considering the variety of warehouse construction and climate represented in the Sissenwine study, it would appear justified to use these lines to predict Top Carton Air mean monthly temperatures from Outside Air temperatures for warehouses of the same type of construction and to prepare temperature frequency distributions supported by the consistency of hourly temperature variability shown for Richmond.

D. Prediction of Actual and Effective Mean Warehouse Temperatures with Relation to Sterile Food Degradation

As in other storage temperature studies, major objectives are to describe observed food storage temperature history, to predict food storage temperature where only climatic statistics are available, and to predict total degradation or effective degradation rate and the corresponding constant effective mean temperature for degradation which may be used in laboratory simulation of the predicted storage stress.

If one assumes a Q_{10} for sterile food degradation of 2, which appears to be the best single compromise figure for the great variety of food degradation temperature coefficients known[1], and a temperature at which degradation is designated as unity (for this study, 70°F), relative degradation at any other temperature may be computed logarithmically.[2] The relation is approximate, but adequate for this purpose Thus, the relative degradation rate for each observed monthly mean Top Level Warehouse Air temperature has been computed The mean of the several monthly rates is the effective degradation rate and corresponds to a temperature known as the effective mean annual temperature, storage at which would produce the same total degradation as would be experienced under the fluctuating temperatures of actual storage. To be sure, a correction of about plus 1 F° should be added to this to represent the effective averaging of all the hourly temperatures which go to make up the monthly mean. Such a computation of the effective increment, using the frequency distributions for November 1956, April 1957, and April 1958 is shown in Tables LXXX, LXXXI, and LXXXII. The Fall and Spring months were

[1]Personal conversation, Mr. Albert Henick, Head, Reaction Mechanisms Group, Food Chemistry Division, Food Laboratory, US Army Natick Laboratories. Q_{10} here refers to increase in degradation rate for every 10°C (18°F) increase in temperature.

[2]For details of the method see Reference 8.

chosen because they have the greatest variability of temperature and would, therefore, be expected to produce the greatest difference between arithmetic and effective monthly mean temperature. The effective mean monthly storage temperature for July at Richmond is 81 and for the whole year it is 67°F.

Effective mean monthly temperatures for the hottest month and for the whole year derived for the fifteen Army warehouses mentioned above have been plotted together with arithmetic mean Top Level Warehouse Air and Outside Air temperatures, in Figs. 5 and 6. The difference between effective mean and arithmetic mean is never more than 8 F° and may approach zero in maritime tropical stations such as Hawaii or Corozal (Panama). Prediction of monthly mean storage temperatures may be made, using the regression equation of Fig. 54 for warehouses of a construction type corresponding to one of those shown in the Tables. Computation of effective mean storage temperature, degradation rate and storage life may then be carried out as outlined above. For periods less than a year, storage life at any given station will be a function of season of storage A computation of storage life for such a short period should always be based on individual months rather than the effective mean annual storage temperature

E. Frequency of Ventilation Hours, by Classes of Temperature Differential Between Inside and Outside Air

Manually-actuated ventilation between the night-time hours of 2000 and 0800 was carried on from 17 August to 6 December 1956 and

from 10 February to 16 April 1957 (eight months). Automatically-actuated ventilation with improved intakes was used from 16 April 1957 to the end of the test, 12 May 1958 (thirteen months), during the hours 1700 to 0730.

Tables LXXXIII-LXXXVIII and Figs. 22-50 show by month and by total period the frequencies of ventilation for the test period both for hours of actual ventilation and of predicted satisfactory ventilation by classes of inside-outside temperature differential.

1. Predicted Satisfactory Ventilation

Temperature and relative humidity observations were planned so that an analysis could be made of hours during which ventilation was useful. The necessary conditions were as follows: 1) temperature of outside air must be below air temperature at high level in ventilated warehouse, 2) dewpoint of outside air must be below dewpoint in ventilated warehouse at floor level, 3) outside air temperature must be greater than dewpoint in ventilated warehouse at floor level

The first condition guarantees that part of the warehouse will be cooled by the introduced air The second requires that no air of greater absolute humidity than that already present will be allowed to enter the warehouse. The third ensures that outside air will not chill cartons near the air intakes resulting in local moisture deposition during intermittent ventilation

Figs. 22-24 for the total periods for the years 1956, 1957, 1958 provide a quick overview of the frequency of satisfactory ventilation hours by classes of inside-outside air temperature differential.

The following table, derived from the graph, shows the pertinent statistics for hours of ventilation.

Table LXXXIX. Percentage of Hours with Predicted Satisfactory Ventilation

Year	Total Hours with Predicted Beneficial Ventilation Conditions	Total Hours[a]	Percent Hours	Percent of Hours with Predicted Beneficial Ventilation when Temperature Differential Between Inside and Outside Air was Equal to or Greater than 9 F°.
1956	949	3629	26	53
1957	1601	7190	21	29
1958	822	3032	27	13

[a]Total hours here means hours of simultaneous temperature and humidity observations.

The year 1957 may be taken as the most representative, since it included data for eleven of twelve months. About 20% of the hours were satisfactory for ventilation and 30% of these hours had a differential equal to or greater than 9 F°. It

should be remembered that although these are predicted figures, they are derived from data on the ventilated warehouse bay, and that during much of the period, ventilation was actually in progress They, therefore, represent cooling potential in excess of that used by the existing system.

The hours between noon and midnight are most favorable to satisfactory ventilation This is shown by Fig. 52, which was prepared from the data for August 1957. The diurnal variation of dewpoint is also indicated. The fewest hours of predicted satisfactory ventilation occur between midnight and sunrise. This is surprising when one considers that the hours before sunrise have the lowest outside air temperatures. Also surprising is the fact that between noon and sunset a large proportion of the hours of predicted satisfactory ventilation are recorded.

Inspection of the data, however, shows that although the temperature of the outside air rises during the day, the high level warehouse air heats up even more, so that beneficial ventilation can occur during the hot hours of the day. A detailed analysis of the reasons for the beginning or ending of predicted satisfactory ventilation is shown in Table XC.

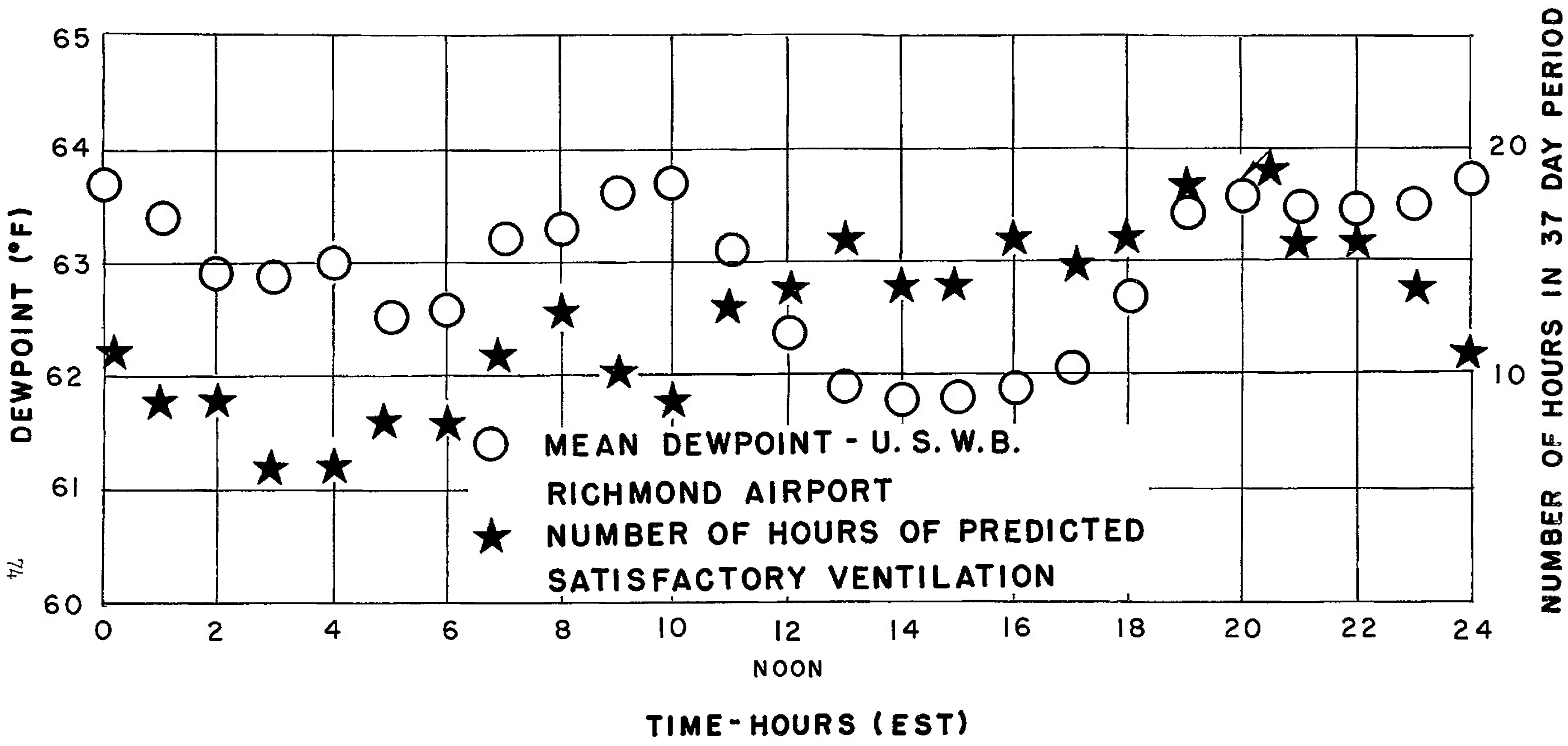

Figure 52 Diurnal variation of outside dewpoint and probability of predicted satisfactory ventilation - August 1957.

Table XC. Causes of Beginning and Ending of Predicted Satisfactory Ventilation

August 1957

	Condition	Beginning	Ending	Frequency (no. of occurrences)
a.	Outside dewpoint higher than inside dewpoint - outside dewpoint rose		X	13
b.	Outside temperature lower than inside dewpoint - outside temperature fell		X	5
c	Outside temperature higher than inside temperature at upper level - outside temperature rose		X	3
d.	Outside dewpoint higher than inside dewpoint - inside dewpoint fell		X	2
e.	Outside temperature lower than inside temperature at high level - outside temperature fell	X		8
f	Outside temperature greater than inside dewpoint - outside temperature rose	X		7
g	Outside dewpoint lower than inside dewpoint - outside dewpoint fell	X		7
h.	Outside dewpoint lower than inside dewpoint - inside dewpoint rose	X		1

The chief cause of the ending of conditions of predicted satisfactory ventilation was the increase in outside dewpoint, while the causes for the beginning of such conditions were more varied. The time distribution of these beginning and ending conditions is shown in the following table.

Table XCI Time Distribution of Beginning and Ending Conditions for Predicted Satisfactory Ventilation, August 1957

Condition Type[a]	Time Period and Number of Occurrences		
	Midnight to 0800	0900 to 1600	1700 to Midnight
Most frequent beginning condition	f (7)	g (4)	e (7)
Most frequent ending condition	b (4)	a (5)	a (5)

[a]Letter refers to designators of Table XC

During the hours from sunrise to midnight, in those cases where predicted satisfactory ventilation conditions no longer exist, it is usually because outside dewpoint has risen above inside dewpoint During the early morning hours after midnight, the fall of the outside temperature below inside dewpoint is the chief cause of the ending of conditions of satisfactory ventilation.

It is plain that dewpoint differentials are critical to the occurrence of satisfactory ventilation conditions as specified for this study In only 11 out of 36 occurrences of the

beginning or ending of satisfactory conditions was temperature differential alone the governing factor.

2. Actual Ventilation

An analysis was also made of frequency of hours of actual ventilation. The graphs (Figs. 22-24) for the total period of the years 1956, 1957, 1958, give the following values shown in Table XCII.

Table XCII. Percentage of Hours with Actual Ventilation

Year	Total Hours of Actual Ventilation	Total Hours[a]	Actual Hours as Percent of Total	Percent of Hours with Ventilation when Temp. Diff. between Inside and Outside Air was Equal to or Greater than 9 F°
1956	1396	2684	52	58
1957	3791[b]	7785[b]	49	38
1958	1586	3234	49	25

[a] Includes all hours of all days during which ventilation was practiced part of the day and temperature recordings were being made of both inside and outside air temperatures.

[b] January omitted because data were missing.

Actual ventilation hours occurred about twice as frequently as predicted conditions for beneficial ventilation and a larger percentage of the hours had temperature differentials greater than 9 F°.

F. Effects of Insulation and Ventilation

The cumulative result of conditioning treatments is best seen in the Top Carton Air temperature differentials between control and ventilated bays, since mean carton air temperatures approximate mean food temperatures and for this reason are critical to the study. Table XCIII and Figure 53 shows these differentials for periods corresponding to various types of treatment.

In general, the temperature differentials produced by ventilation and insulation are low and range between one and two Fahrenheit degrees

The effect of insulation alone is shown in the mean air temperature differential value of 1.85 F° for the period April through July 1956. In contrast, the maximum effect of ventilation is shown by the difference between that figure and 4.25 F°, for the similar period in 1957, when both insulation and ventilation were operative The difference is 2.4 F°.

Throughout the study, no difficulties were experienced arising from humidity changes caused by ventilation

Table XCIII. Temperature Differential Between Top Carton Monthly Mean Air Temperature in Control Bay Versus Ventilated Bay for Selected Periods of Insulation and Ventilation

Period (Inclusive)	Treatment	Temperature Differential (°F)
April - July, 1956	Reflective insulation	1 85
Sept - March, 1956-57[a]	Manually actuated ventilation and reflective insulation	1.42
May - May, 1957-58	Automatically actuated ventilation and reflective insulation	2.75
Sept - March. 1956-57[a]	Manual ventilation	1.42
Sept - March. 1957-58[a]	Automatic ventilation	1.88
April - July, 1956	Insulation	1 85
April - July, 1957	Insulation and ventilation	4 25

[a] January 1957 omitted because data were missing January 1958 omitted to give comparable means

DIFFERENCE BETWEEN TOP CARTON MONTHLY MEAN AIR TEMPERATURE IN CONTROL BAY VERSUS VENTILATED BAY 1956- 1958

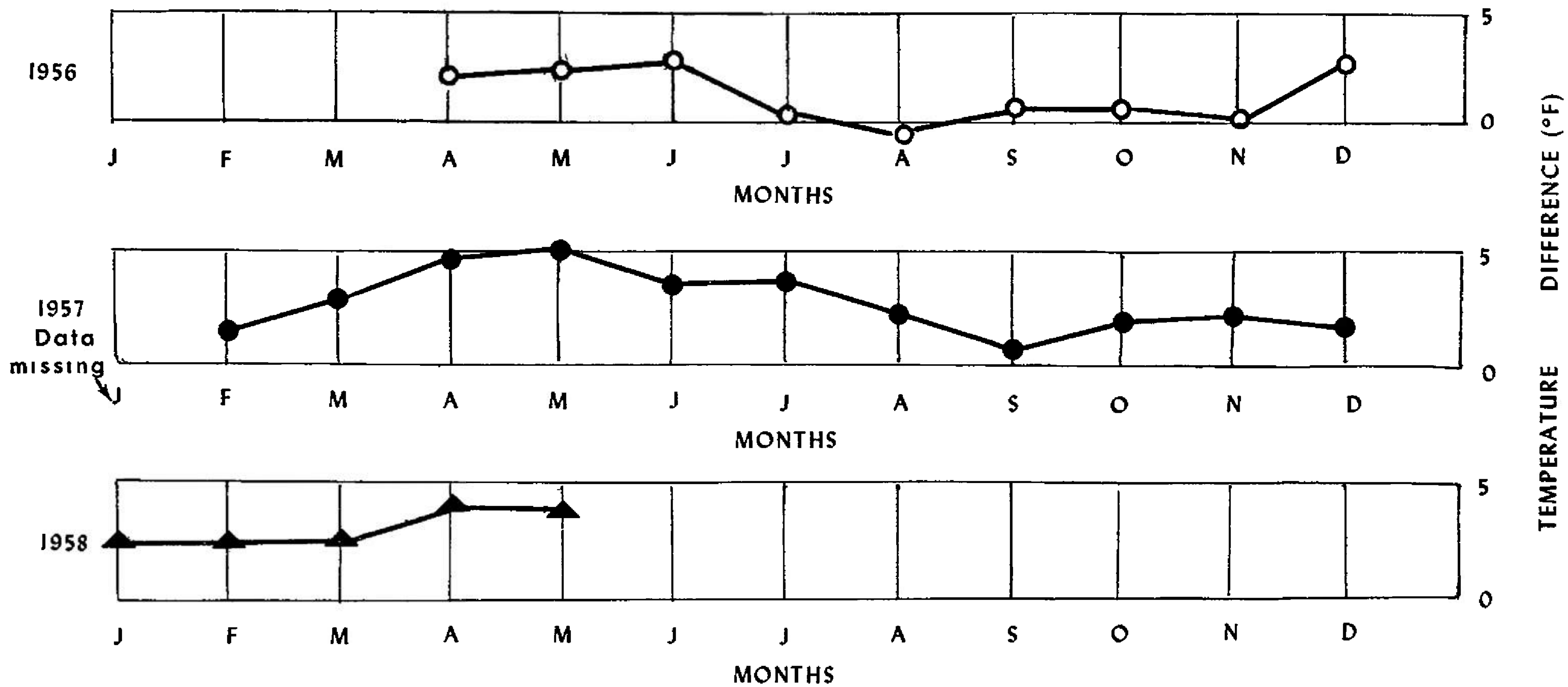

Figure 53. Difference between top carton monthly mean air temperatures in control bay versus ventilated bay - 1956, 1957, 1958.

Conclusions

A. Food Storage Life in Ventilated and Unventilated Warehouses

The greatest all-year temperature differential between ventilated and non-ventilated bays produced by both insulation and ventilation was from May 1957 to May 1958, for which 2.75 F° was the mean of all monthly carton air temperature differential values. This is equivalent to only an 11 percent difference in reaction rate or increase in storage life for a Q_{10} of 2. During the period April through July 1957, however, the figure 4 25 F° corresponds to an 18 percent difference in reaction rate, or an increase in storage life of 18% for the late spring and early summer months

B. Recommendations

These moderate increases in storage life would not appear to justify the costs of modification and the inconveniences of the partially sequestered storage However, the extent of extra available cooling potential revealed by the frequency diagrams of Figs 22-50 and Tables LXXXIX and XCII during periods in which ventilation was being carried on, suggests that the installations of more fans, rather than any increase of power in the presently installed fans, would result in a considerably higher degree of cooling than was demonstrated by the relatively meager equipment of this study

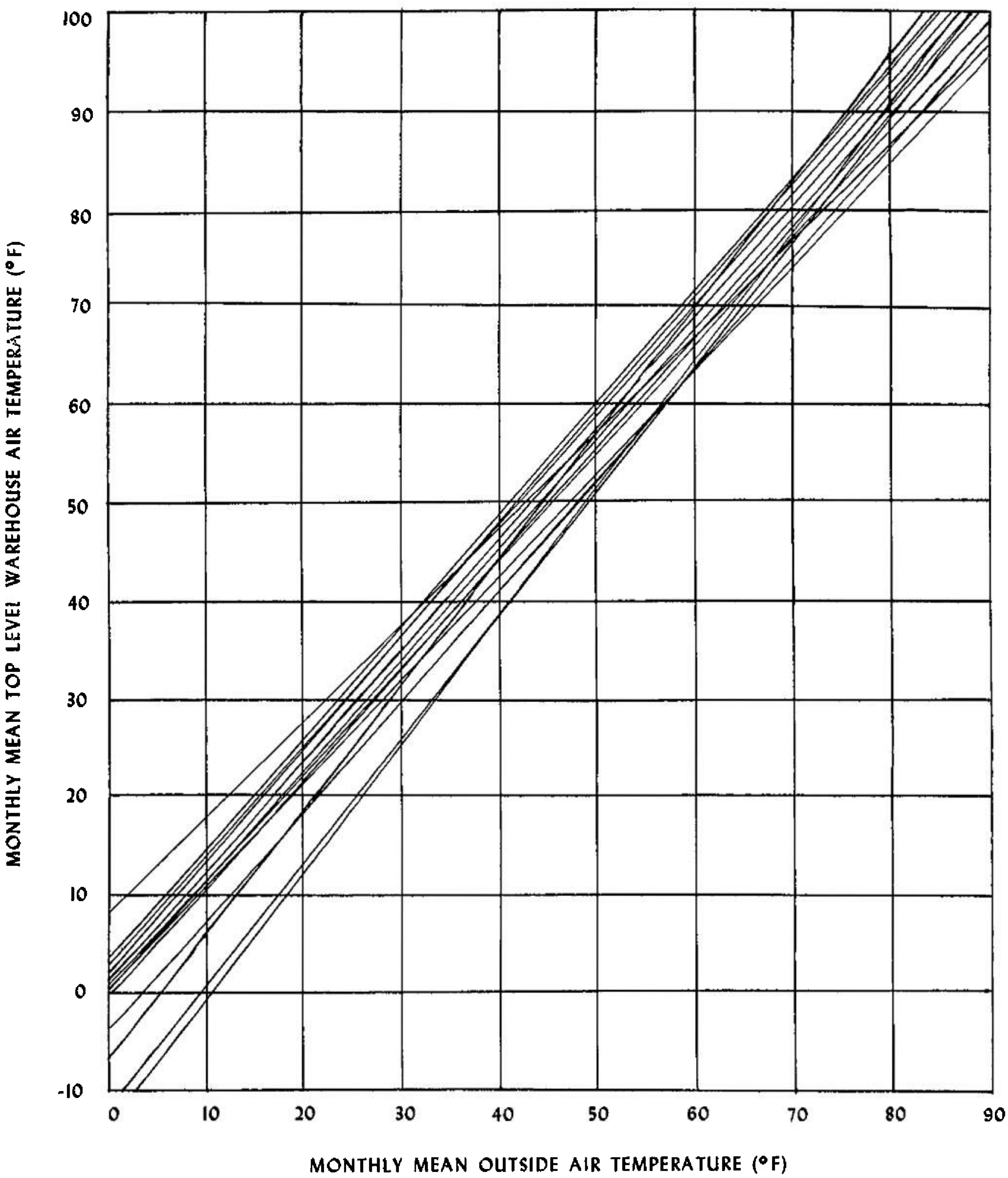

Figure 54 Linear regression lines for variation of monthly mean top level warehouse air temperature with outside air temperature at 15 US Army warehouses.

Acknowledgements

Many individuals and agencies contributed to the planning and execution of this study Space permits mention of only those most directly involved

The study was the outcome of a request from Mr George W Kitzmiller, then Chief, Care and Preservation Section, Field Service Division, Office of the Quartermaster General, Washington, D C and from the Commandant, Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois. In the planning and implementation of the study, both Mr. Kitzmiller and Dr Harry E. Goresline, Associate Scientific Director, QMF&CI, were greatly involved Mr William G Kurtz, who succeeded Mr Kitzmiller on the latter's retirement in May 1957, was also of great assistance

At Natick, much help was received from Dr. Austin Henschel, Chief, Environmental Protection Research Division, EPRD, and Dr. David H Miller, Chief, Environmental Analysis Branch This Division has since been redesignated the Earth Sciences Laboratory Dr William B Brierly, Chief, Military Applications Division of Earth Sciences Laboratory, the writer's supervisor during much of the work, has been particularly helpful in suggestions and criticism

SP3 Nico Roos, of the Environmental Analysis Branch of EPRD, was most directly concerned with installation and recording

Mr Willard Morse, of the same branch, performed the arduous and detailed work of data reduction The accuracy and consistency of the encoding of the very large body of data is largely his accomplishment. Mr Ronald J. Geronomini and Mr. David M. Gracia performed the computer data processing. Miss Gertrude Barry, Cartographer, made most of the charts and maps. SP5 Vernon Couch also gave valuable cartographic assistance

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The tedious but accurate typing and final organization of the report was done by Miss Evelyn M. Zicko of the Food Laboratory, the present assignment of the senior author.

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APPENDIX A

Frequencies, period means, and standard deviations of hourly observations for total yearly periods - Tables VI-VIII and Figures 22-24.

TABLE VI

PERCENTAGE FREQUENCIES, MEANS AND STANDARD DEVIATIONS OF HOURLY OBSERVATIONS FOR TOTAL YEAR 1956

POSITION	Temperature (F) 44 5	46 7	48 9	50 1	52 3	54 5	56 7	58 9	60 1	62 3	64 5	66 7	68 9	70 1	72 3	74 5	76 7	78 9	80 1	82 3	84 5	86 7	88 9	90 1	92 3	S_x	$\bar{X}$	N
TOP CARTON AIR TEMPERATURE VENTILATED BAY		3	1	1	4	9	3	1	2	5	6	8	9	4	4	4	4	5	10	7	6	2				11 1	69 D	5764
TOP CARTON AIR TEMPERATURE CONTROL BAY		2	2	1	3	4	5	3	2	2	6	8	7	5	4	4	4	5	11	11	6	2				10 8	70 1	5764
BOTTOM CARTON AIR TEMPERATURE VENTILATED BAY		2	3	2	7	4	4	3	3	3	14	7	6	3	7	4	11	10	6							9 8	66 7	5764
BOTTOM CARTON AIR TEMPERATURE CONTROL BAY			2	3	6	4	2	4	4	2	6	13	6	5	2	5	6	12	12	4						10 1	68 4	5764
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK VENTILATED BAY	1	2	1	1	4	5	5	2	3	3	7	7	7	6	4	4	4	5	8	7	6	4	2			11 6	69 8	5763
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK CONTROL BAY	1	1	2	2	2	3	3	3	3	4	5	8	6	5	5	4	5	8	8	6	4	4	3	2	1	11 8	70 9	5764

	Temperature (°F) 25 9	30 4	35 9	40 4	45 9	50 4	55 9	60 4	65 9	70 4	75 9	80 4	85 9	90 4	S_x	$\bar{X}$	N
U S W B AIR TEMPERATURE BYRD FIELD	1	2	3	5	6	9	11	12	13	14	8	6	4	2	14 9	63 5	6608

TABLE VII

PERCENTAGE FREQUENCIES MEANS AND STANDARD DEVIATIONS OF HOURLY OBSERVATIONS FOR TOTAL YEAR 1957

POSITION	Temperat (F)																														S_x	$\bar{X}$	N
BOTTOM CARTON AIR TEMPERATURE VENTILATED BAY								2	5	8	7	9	6	4	3	2	3	3	5	4	7	1	3	13	12	3					11 7	61 4	8008
BOTTOM CARTON AIR TEMPERATURE CONTROL BAY								1	2	6	7	5	8	5	4	3	2	3	3	3	4	5	4	5	8	10	6	2			12 2	63 9	8008
LOW LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK VENTILATED BAY							1	3	4	7	6	7	6	5	4	3	3	2	3	4	4	5	3	7	12	7	2				12 4	61 7	8008
LOW LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK CONTROL BAY							1	2	5	6	5	5	6	5	5	3	2	3	4	2	3	4	5	5	6	7	8	5	2	1	13 5	63 7	8008
INTAKE AIR TEMPERATURE LOW LEVEL	1	1	2	2	2	2	3	3	5	5	5	5	5	5	3	3	3	3	3	4	6	5	5	5	6	4	2	1			14 2	58 6	8005
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH NEXT TO STUDY STACK VENTILATED BAY						1	1	3	5	7	8	6	5	4	2	2	3	3	3	3	4	5	2	8	13	8	2				12 9	62 0	7541
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY						1	2	3	5	6	4	4	4	4	4	3	2	3	3	3	3	4	5	5	5	7	7	6	5	2	14 3	64 4	7758
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH IN C BAY°						2	3	5	9	8	9	5	3	2	1	1	1	2	1	2	4	6	5	4	5	6	6	4	2	1	14 8	60 6	5702
WAREHOUSE FLOOR SURFACE TEMPERATURE							1	2	3	6	7	7	8	5	4	3	3	3	4	4	7	2	3	15	10	2					11 5	61 6	8008
TOP CARTON AIR TEMPERATURE VENTILATED BAY							1	2	4	7	6	8	6	6	4	2	3	2	2	3	2	4	5	2	5	12	11	2			13 1	63 3	8008
TOP CARTON AIR TEMPERATURE CONTROL BAY								1	2	5	6	5	6	4	6	5	1	3	2	3	3	1	4	5	6	5	6	9	6	3	13 7	66 0	8008
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK VENTILATED BAY							1	3	3	7	6	6	6	6	5	3	2	3	2	2	3	3	4	5	6	7	6	4	3	2	1	14 0	63 7	8008
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK VENTILATED BAY								1	1	1	2	4	5	5	6	7	8	10	10	9	10	8	5	3	2	1					8 0	62 2	7758
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY									1	1	2	3	6	8	9	9	11	12	10	9	6	4	3	2	1	1					7 9	61 8	7733
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK C BAY°					1	1	1	2	2	3	5	6	7	7	9	8	10	9	7	5	5	5	3	1	1						9 0	58 2	7734

	T mp at (F)																					
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK CONTROL BAY								3	10	12	11	8	8	9	12	11	7	4	1		14 7	66 9	8008
EXHAUST AIR TEMPERATURE							1	6	12	11	9	8	6	9	13	10	4	3	2	2	16 3	66 4	8008
OUTSIDE AIR TEMPERATURE RICHMOND DEPOT					1	4	6	7	8	7	9	9	11	12	8	6	5	2			16 7	60 6	7987
U S W B AIR TEMPERATURE BYRD FIELD			1	1	2	5	8	8	7	8	9	9	11	10	7	5	4	2			16 6	48 3	8758
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH NEXT TO STUDY STACK VENTILATED BAY				2	7	11	13	10	5	8	13	18	10								13 7	48 8	7530
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY				1	4	8	14	13	7	8	10	19	13	1							13 0	50 8	7721
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH IN C BAY°				5	12	18	12	5	3	7	13	16	7								14 6	45 5	5691
U S W B DEWPOINT BYRD FIELD	1	1	3	5	6	9	10	7	6	9	11	12	13	6							17 6	58 5	8759

°P ... loc ted S.E. Cor ... Ap ... Octob ... N ember

TABLE VIII

PERCENTAGE FREQUENCIES, MEANS AND STANDARD DEVIATIONS OF HOURLY OBSERVATIONS FOR TOTAL YEAR 1958

POSITION	5	6-7	8-9	10-1	2-3	14 5	16-7	8 9	20-1	22 3	24-5	26-7	28-9	30-1	32-3	34-5	36-7	38-9	40-	2 3	4-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60	62-3	64-5	66-7	68-9	70-1	72 3	74-5	76-7	78-9	80-	82 5	s	X	N
BOTTOM CARTON AIR TEMPERATURE VENTILATED BAY															1	4	11	9	12	11	14	7	4	4	1	1	2	10	7												8 0	45 6	3189
BOTTOM CARTON AIR TEMPERATURE CONTROL BAY																	2	9	13	9	12	12	9	4	4	1	1	1	2	10	6	1									8 6	48 5	3190
LOW LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK VENTILATED BAY														2	3	4	8	9	8	12	11	9	4	4	1	2	2	5	9	4	1										9 0	45 7	3190
LOW LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK CONTROL BAY															2	4	7	9	8	9	12	9	6	5	3	2	1	2	3	6	6	3	1								9 9	47 4	3190
INTAKE AIR TEMPERATURE LOW LEVEL								1	1	1	1	2	3	3	5	6	7	7	8	8	7	6	3	4	2	2	2	6	6	3	1										11 5	42 9	3190
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH NEXT TO STUDY STACK VEVENTILATED BAY														1	3	5	9	10	7	11	10	9	4	5	2	1	2	6	8	4	1										8 8	45 7	3154
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY															1	3	5	6	9	10	11	10	6	4	5	3	2	3	3	3	5	3	3	1							9 9	49 1	3167
LOW LEVEL WAREHOUSE AIR TEMPERATURE HYGROTHERMOGRAPH IN C BAY															1	2	5	8	10	10	8	10	8	6	4	2	2	2	4	6	4	3	1								9 8	48 7	3147
WAREHOUSE FLOOR SURFACE TEMPERATURE															3	3	7	9	10	14	12	10	4	4	1	2	2	10	7	1											8 2	45 8	3190
TOP CARTON AIR TEMPERATURE VENTILATED BAY																4	12	9	11	8	13	11	2	6	1	2	1	1	9	9	1										8 8	46 4	3188
TOP CARTON AIR TEMPERATURE CONTROL BAY																1	4	11	10	8	10	10	8	5	4	2	1	1	1	3	7	6	4								9 8	49 2	3190
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK VENTILATED BAY														2	3	4	8	8	8	9	12	8	6	4	2	2	2	3	6	5	4	2									9 9	46 5	3190
HIGH LEVEL WAREHOUSE AIR TEMPERATURE NEXT TO STUDY STACK CONTROL BAY															1	3	4	7	8	8	9	10	8	5	4	2	2	3	3	4	4	3	3	2	2	1	1	1			11 3	50 5	3189
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH NEXT TO STUDY STACK VENTILATED BAY			2	1	2	3	5	4	5	4	6	6	8	8	9	5	4	4	2	1	2	3	4	4	6	1	1														12 1	32 6	3138
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY								1	3	6	6	8	8	12	12	12	5	2	1	2	2	3	4	4	4	2	1														9 4	35 3	3167
LOW LEVEL WAREHOUSE DEWPOINT HYGROTHERMOGRAPH IN C BAY						1	4	7	5	6	4	7	9	6	8	5	4	2	2	2	4	3	6	4	4	1	1														11 8	33 7	3138
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK VENTILATED BAY														1	1	1		2	2	3	2	3	5	5	7	6	5	5	6	5	4	5	6	4	4	3	3	3	4	2	12 5	59 4	3154
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK CONTROL BAY																					1	2	4	6	8	9	12	12	10	8	6	5	6	3	1	1					6 9	58 9	3170
LOW LEVEL WAREHOUSE RELATIVE HUMIDITY HYGROTHERMOGRAPH NEXT TO STUDY STACK C BAY																1	2	3	4	6	7	4	5	6	5	4	5	6	6	6	6	4	3	4	5	2	1		1		11 2	56 1	3138

	Temperature (°F) 0-4	5-9	10-	15-9	20-	25-9	30-4	35-9	40-	45-9	50-4	55-9	60-4	65-9	70-	75-9	80-4	s	X	N
EXHAUST AIR TEMPERATURE						1	7	15	20	18	7	7	8	5	3	2	1	13 4	49 3	319D
OUTSIDE AIR TEMPERATURE RICHMOND DEPOT			1	3	3	6	11	12	13	13	9	8	6	4	3	2	1	15 5	44.8	3181
U S W B AIR TEMPERATURE BYRD FIELD			1	3	3	7	11	13	12	10	8	7	7	6	4	3	1	16 2	46 8	3616
U S W B DEWPOINT BYRD FIELD	1	3	6	8	7	11	13	11	9	7	6	6	7	1				16 0	35 6	3607

FREQUENCIES, PERIOD MEANS, AND STANDARD DEVIATIONS OF HOURLY OBSERVATIONS TOTAL PERIOD 1956

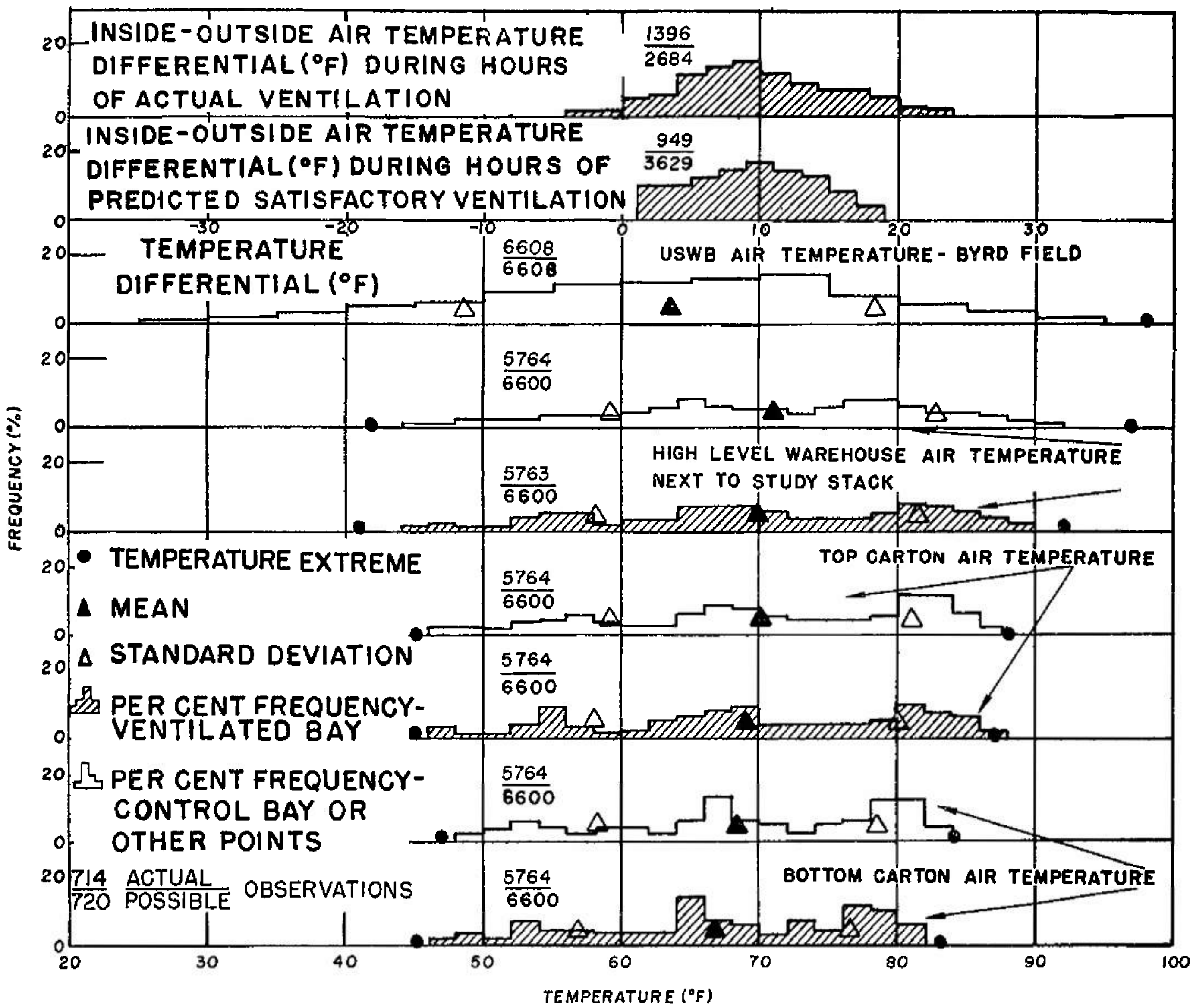

Figure 22 Frequencies, period means, and standard deviations of hourly observations for total yearly period, 1956

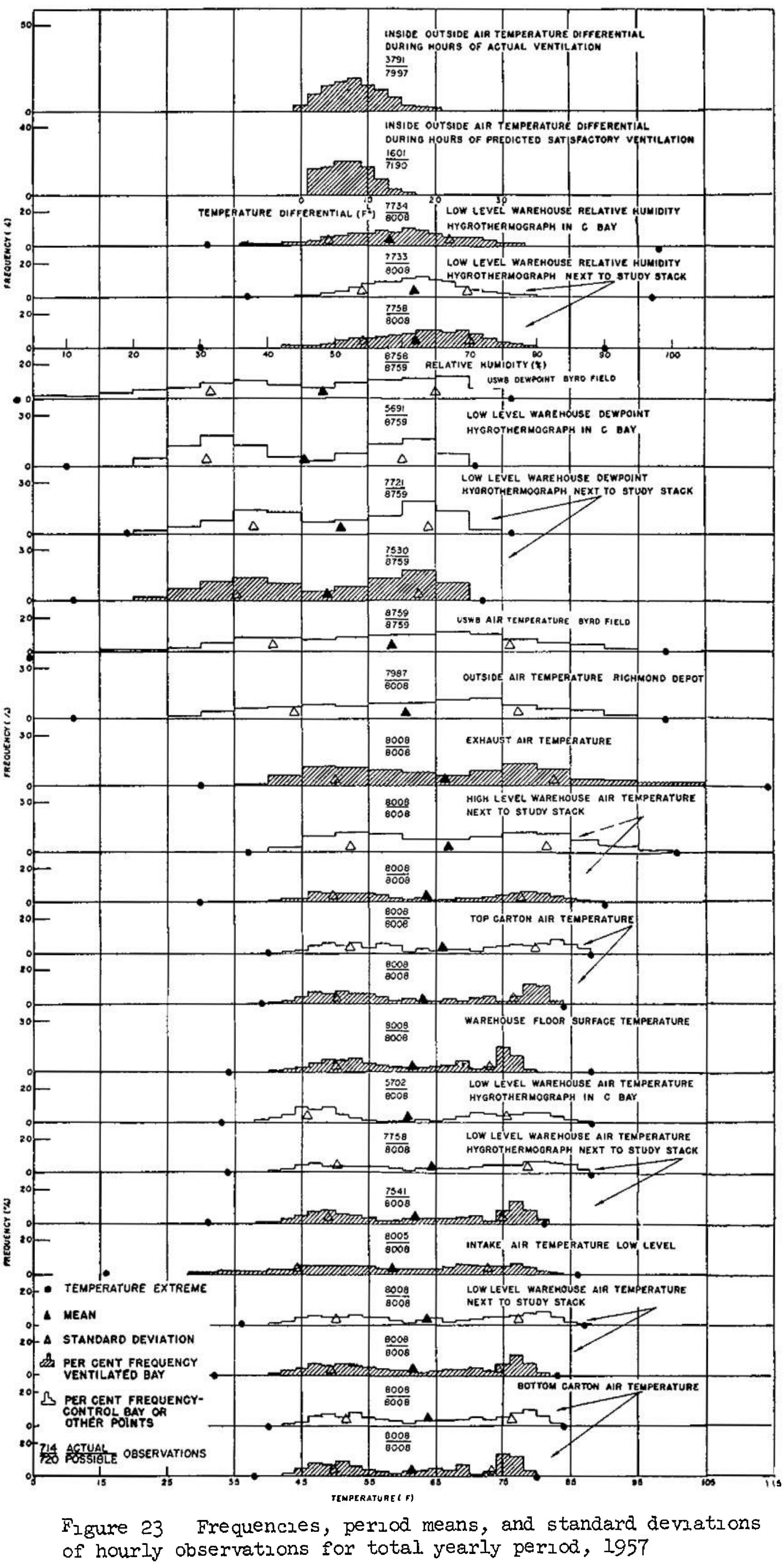

Figure 23 Frequencies, period means, and standard deviations of hourly observations for total yearly period, 1957

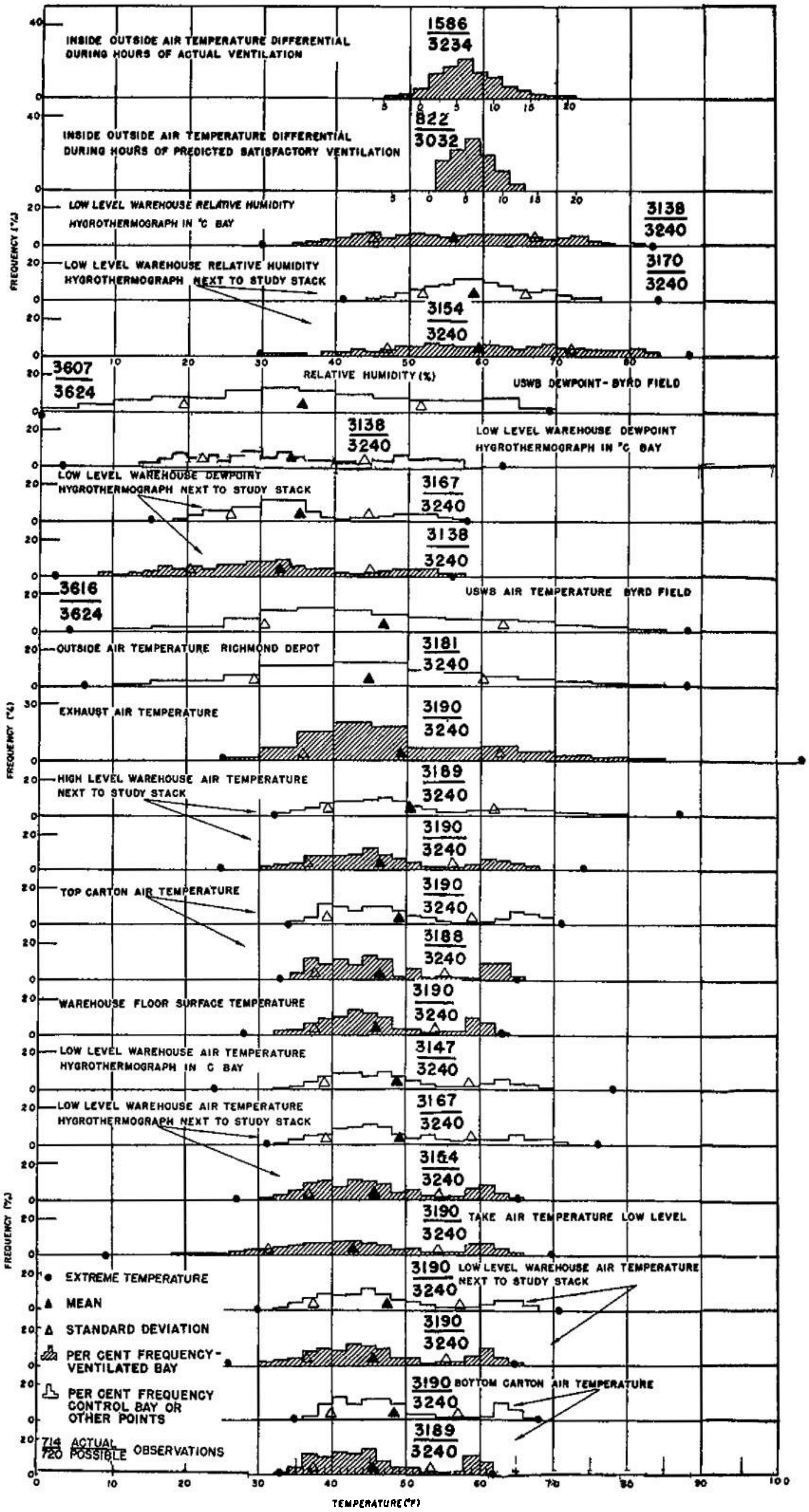

Figure 24. Frequencies, period means, and standard deviations of hourly observations for total yearly period, 1958.

APPENDIX B

Frequencies, period means, and standard deviations of hourly observations by months - Tables IX-LXXVII and Figures 25-50.

Table IX

Percentage Frequencies, Means, and Standard Deviations of Hourly Observations by Months - 1956
Bottom Carton Air Temperature - Ventilated Bay
Temperature (^{o}F)

Month	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	S_x	$\bar{x}$	N
Apr			3	8	54	25	7	2													1 8	53 0	688
May								19	19	10	46	5									2 6	62 4	741
Jun												26	12	9	29	14	9				3 3	70 8	717
Jul																	54	42	4		0 9	77 6	726
Aug																	20	19	56	5	1.7	79 3	585
Sep												1	11	13	25	21	6	22	1		3 3	73 9	719
Oct										10	54	11	21	3							2 0	65 7	741
Nov		9	13	4	5	14	22	5	4	6	6	13									6 3	56.2	704
Dec	4	40	36	19																	1 6	48 0	144

Table X

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Top Carton Air Temperature - Control Bay
Temperature (^{o}F)

Month	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	86-7	88-9	S_x	$\bar{x}$	N
Apr				2	17	28	24	14	5	2	3	4	2											3 8	56 6	688
May									4	10	11	17	26	17	7	6	1							3 6	67 8	741
Jun													6	9	9	13	10	9	18	18	8			4 8	77 5	717
Jul																		13	32	31	16	6	1	2 2	81 9	726
Aug																	3	10	24	30	21	11	1	2.5	82 3	585
Sep													10	7	9	12	17	14	15	11	4	1		4.6	76.6	719
Oct										2	31	35	10	11	10	2								2.9	67.2	741
Nov		8	14	3	4	9	18	12	5	7	6	9	4											6 5	56 7	704
Dec	2	26	23	14	20	3	11																	3 2	50.0	144

Table XI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Air Temperature Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	S_x	$\bar{x}$	N
Jun																	7	32	39	22				1.7	76.0	440
Jul																			2	37	50	11		1.3	80.0	726
Aug																		2	11	12	19	38	17	2.5	81 1	585
Sep													1	9	12	13	18	18	7	12	9			4 2	73.3	719
Oct									1	2	5	12	42	17	11	11								2.8	65.3	741
Nov	0	4	7	10	8	6	8	12	12	9	4	4	4	8	3									7 2	54.6	704
Dec	1	7	8	29	19	19	10	7																3 1	48.4	144

Table XII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
High Level Warehouse Air Temperature Next to Study Stack - Control Bay
Temperature (^{o}F)

Month	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	S_x	$\bar{x}$	N
Apr		5	27	33	18	9	4	2					6 4	58 1	688
May				3	22	31	25	14	3	1			6.1	69 2	741
Jun						10	17	27	21	14	9		6.9	78 8	717
Jul								27	41	21	9	1	4 6	82 7	726
Aug							1	19	40	26	12	1	4.7	83 6	585
Sep						15	24	26	23	10	1		6 1	76 5	719
Oct				1	27	44	21	6	1				4.3	67 5	741
Nov	5	20	18	23	15	16	2						7 6	56 1	704
Dec	8	37	25	18	7	3							5.8	51 7	144

Table XIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Intake Air Temperature - Low Level
Temperature (^oF)

Month	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	S_x	$\bar{x}$	N
Jun										36	64			2 0	75.3	440
Jul											62	38		1.3	79 1	726
Aug								1	1	8	23	64	2	3.9	79.3	585
Sep					1	6	11	14	20	33	11	4		7.6	67.5	719
Oct			1	2	3	9	16	39	26	1				6 4	60 5	741
Nov	5	7	14	16	11	21	10	8	6					10.7	47 2	704
Dec	1	6	14	19	38	12	7							6.6	44 5	144

Table XIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Exhaust Air Temperature
Temperature (^{o}F)

Month	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	100-4	105-9	S_x	$\bar{x}$	N
Jun						5	18	23	12	9	9	9	10	3	11 1	83 9	440
Jul							9	32	19	12	15	8	5	1	8 9	84 0	726
Aug					1	1	1	21	29	15	12	10	8	1	8 9	86 0	585
Sep					1	19	20	19	23	9	5	3			8 0	77 3	719
Oct				4	22	39	20	8	4	2					6.1	68 2	741
Nov	11	17	21	19	12	9	8	1							8.8	55 5	704
Dec	14	37	12	14	9	7	5								8 4	52.0	144

Table XV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Top Carton Air Temperature - Ventilated Bay
Temperature (^{o}F)

Month	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	86-7	S_x	$\bar{x}$	N
Apr			2	2	21	59	5	3	4	2													2.4	54 5	688
May									10	22	7	32	27	1									2.7	65.5	741
Jun													11	19	8	8	20	21	12				3.8	74 8	717
Jul																			60	22	18		1.6	81 6	726
Aug																		16	8	20	39	16	2 4	83.1	585
Sep													11	3	16	21	16	8	5	17	3		4 4	75 9	719
Oct										11	39	21	9	11	8								2.7	66 5	741
Nov		19	3	2	8	15	19	3	4	5	3	6	11										7 1	56 2	704
Dec	13	44	27	14	1																		1 8	47 3	144

Table XVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Outside Air Temperature - Richmond Depot
Temperature ($^{\circ}F$)

Month	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	S_x	$\bar{x}$	N
Jun								1	8	13	26	14	13	15	10	8.7	77 0	440
Jul								1	6	9	29	21	16	12	5	7 8	76 2	726
Aug									3	12	26	22	16	15	5	7.5	77.2	584
Sep						1	6	16	15	15	22	11	6	5	1	9 9	68.0	718
Oct				1	4	4	11	18	29	18	8	3	1			8 6	60 8	741
Nov	1	7	9	17	11	12	10	10	8	7	5					12.8	47.3	703
Dec		3	9	13	7	25	9	14	4	8						11.9	49.1	144

Table XVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Bottom Carton Air Temperature - Control Bay
Temperature (°F)

Month	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	s_x	$\bar{x}$	N
Apr		1	7	48	32	3	3	4													2.2	53.6	688
May							5	24	8	9	42	11									2.6	62.4	741
Jun											4	17	13	6	14	18	23	5			4.2	74.1	717
Jul																1	51	41	8		1.2	79 6	726
Aug																12	14	49	25	1	1 7	80.2	585
Sep												7	8	11	25	20	8	14	7		3.8	75.7	719
Oct										29	39	11	20								2.0	66.9	741
Nov		7	14	3	5	17	23	4	6	7	14										5 6	57.7	704
Dec	3	46	33	17																	1.7	49 9	144

Table XVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
High Level Warehouse Air Temperature Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	S_x	$\bar{x}$	N
Apr			36	50	7	6						5 8	56.2	688
May				1	24	51	22	2				3 6	67 0	741
Jun						6	27	36	29			4.2	76.4	717
Jul								7	67	24	1	2 6	82.8	726
Aug								8	40	47	4	3.2	84 3	584
Sep						16	26	30	23	4		5.3	75.7	719
Oct				1	25	48	18	6				4.0	67 0	741
Nov	6	23	17	27	13	9	4					7 7	55.2	704
Dec	12	46	26	13	1							4 1	49.1	144

Table XIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Air Temperature Next to Study Stack - Control Bay
Temperature (°F)

Month	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	86-7	88-9	S_x	$\bar{x}$	N
Jun																7	11	16	27	25	13				2.8	78.4	440
Jul																	3	13	28	29	19	7	1		2 4	80.0	726
Aug																1	3	7	22	29	17	14	6	1	3 0	80 8	585
Sep												1	8	8	11	12	15	13	11	12	6	2			4 9	74 6	719
Oct									3	4	18	25	23	9	10	7									3 3	65.9	741
Nov	3	8	12	6	4	11	13	8	9	6	6	5	4	4											7 1	54.7	704
Dec	5	9	28	11	11	20	2	12	1																4.0	49 5	144

Table XX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Roof Monitor Air Temperature - Ventilated Bay
Temperature (^{o}F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	100-4	105-9	S_x	$\bar{x}$	N
Jun[a]								5	17	21	13	10	10	12	10	1	10 7	84 0	440
Jul[a]								1	10	29	21	13	12	9	4	1	8.5	83 7	726
Aug[a]									3	48	17	10	10	6	4	1	7.7	82 9	585
Sep[b]								18	44	34	3						3 7	73 5	719
Oct							29	56	14								2.5	65 8	741
Nov			1	22	19	32	11	14									6 6	55.6	704
Dec			3	50	46												2 7	49.4	144

[a]Located in roof monitor

[b]Moved to floor surface

Table XXI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Air Temperature - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (°F)

Month	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	S_x	$\bar{x}$	N
Apr						18	44	25	4	3	6												2 5	55 4	647
May										9	16	16	23	28	6	3							3.0	66 0	744
Jun														7	14	13	12	16	29	8			3.6	75 2	720
Jul																			16	51	24	8	1.6	81 0	744
Aug																	3	6	18	19	35	18	2.6	81 2	744
Sep												4	12	9	14	17	11	10	7	13	1		4.8	73 0	720
Oct							1	0	1	4	15	32	25	10	10	1							3 0	65 4	744
Nov	2	9	10	8	3	10	10	14	8	5	5	5	8										7 0	54 6	696
Dec	1	4	7	6	8	28	29	16	1														3 3	52 6	620

Table XXII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack
Temperature (^{o}F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	S_x	$\bar{x}$	N
Apr				1	40	44	14					3.3	55.5	647
May					12	79	9					2.1	57.1	744
Jun					3	54	42					2.5	59.1	720
Jul					19	34	31	14	1			4.8	58.8	744
Aug				4	68	17	7	2				3.8	53.7	744
Sep			2	3	18	30	27	14	4			6.4	58.8	720
Oct				1	16	22	18	23	12	6		7.3	62.5	732
Nov	1	3	7	24	11	15	9	16	9	2	1	10.8	56.2	696
Dec				4	6	8	9	18	36	15	1	8.3	67.7	620

Table XXIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay
Temperature (°F)

Month	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	84 -5	86 -7	88 -9	90 -1	92 -3	S_x	$\bar{x}$	N
Apr					11	27	34	17	1	6	5															2 9	56 6	623
May								1	7	14	18	19	28	11	2											2 1	57 1	744
Jun												1	8	14	15	14	19	17	4	2	2	3	1			4 4	75.2	720
Jul																1	7	14	20	22	15	12	5	2	1	3 5	82 4	744
Aug															1	2	8	13	18	20	15	11	8	3		3 8	82.3	744
Sep											2	9	7	9	12	9	12	12	12	9	3	1				5 5	75.2	720
Oct									4	7	23	29	11	14	9	3	1									3.3	67.0	732
Nov	4	9	8	10	8	11	11	13	7	8	5	2	3													6.3	55.3	720
Dec	2	2	6	9	14	20	24	12	7	4																4 0	55.0	648

Table XXIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack
Temperature (°F)

Month	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	S_x	$\bar{x}$	N
Apr	1	2	28	34	16	8	7	3			6.7	53.3	521
May		4	9	31	36	14	5				5 3	55.2	744
Jun				14	45	34	6				3 8	58.6	720
Jul				3	22	41	25	7			4 7	62 5	744
Aug			2	10	38	34	14				4 4	59.4	744
Sep		1	7	19	26	28	12	5			6.9	58.3	720
Oct			2	14	26	19	27	10	2		6 9	61.6	744
Nov		7	19	15	22	14	4	11	6	1	10 0	57 8	720
Dec			9	9	11	18	32	16	3	1	7.8	63.0	648

Table XXV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Air Temperature - Hygrothermograph in Southeast Corner of Bay
Temperature (^{o}F)

Month	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	84 -5	s_x	$\bar{x}$	N
Apr							10	29	43	7	2	4	4											2.7	56.4	646
May											4	16	15	18	31	12	3							3 0	66 7	744
Jun															6	14	15	18	27	19	1			3.0	74 6	720
Jul																			1	31	51	16	1	1 3	80 1	744
Aug																	1	3	7	19	28	31	10	2 6	80 4	744
Sep												2	9	12	11	11	15	10	8	10	9	1		5 1	72 0	696
Oct								1	2	3	8	23	29	13	9	10								3 4	64.4	720
Nov	4	6	8	11	4	6	8	12	13	7	4	3	3	7	1									7 3	53.1	678
Dec	2	1	6	6	7	12	27	33	6															3 6	51.8	616

Table XXVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Relative Humidity - Hygrothermograph in Southeast Corner of
Ventilated Bay
Temperature ($^{\circ}F$)

Month	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	S_x	$\bar{x}$	N
Apr	1	13	45	23	11	4	1		5 3	49.5	637
May		2	20	64	12				3.2	51.4	724
Jun				46	47	6			2.7	55.2	720
Jul			6	35	43	15			4.0	55.3	744
Aug			19	52	18	8	2		4.5	52 8	744
Sep		4	11	22	27	25	8	2	6.5	56.3	695
Oct		5	12	15	27	25	13	2	7.1	57.3	720
Nov	3	9	25	26	17	9	6	2	7.4	52.7	702
Dec			9	5	20	30	35	1	5.7	60.8	616

Table XXVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
U. S. W. B. Dewpoint - Byrd Field
Temperature (^{o}F)

Month	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	S_x	$\bar{x}$	N
Apr		1	7	15	19	15	6	7	12	7	6	1		12 2	40.3	720
May				2	4	8	11	17	12	15	20	9		10 4	52 7	744
Jun								5	11	21	19	33	9	6.7	62 8	720
Jul									1	10	16	37	35	4 9	67 8	744
Aug									2	13	13	52	20	4 8	66 8	744
Sep					1	2	7	10	22	12	19	14	11	9 6	58 2	720
Oct					2	7	12	15	14	22	23	4		8 6	53 6	744
Nov	2	8	12	18	12	11	10	6	7	6	2	4		13 8	36.4	720
Dec	2	2	9	14	12	9	12	12	19	7				12.0	39 8	744

Table XXVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
U. S. W. B. Air Temperature - Byrd Field
Temperature (^{o}F)

Month	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	S_x	$\bar{x}$	N
Apr			2	8	15	12	15	14	11	8	6	3	3	1			12.5	55 7	720
May				1	1	6	12	14	15	16	13	9	5	2	2		11.6	65.4	744
Jun							2	9	9	16	21	14	12	9	8		10.3	74 5	720
Jul								1	6	13	29	19	13	11	4	1	8.0	76.8	744
Aug								2	9	17	24	18	15	9	4		8.2	75 8	744
Sep					1	2	11	17	11	19	17	8	6	5			10 5	67.1	720
Oct				2	4	5	12	23	29	14	6	3	1				8.4	60.6	744
Nov	1	7	12	13	14	11	13	9	7	8	2						12 6	47 2	720
Dec		5	9	9	15	15	16	15	8	3	2						10.9	48.9	744

Table XXIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Dewpoint - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (°F)

Month	14-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	S_x	$\bar{x}$	N
Apr				2	65	23	9					3.4	39.7	647
May						4	50	42	3			3 1	50.3	744
Jun								20	33	44	2	3 8	59 6	720
Jul									1	67	32	2.0	64.9	744
Aug									22	67	10	2 5	62.5	744
Sep						2	5	39	24	11	18	6 3	57 5	720
Oct					2	8	24	41	22	2		4 9	52.1	732
Nov	1	7	17	14	15	14	14	7	8	1		10 5	39 1	696
Dec			8	10	9	35	35	2				6 2	42 1	620

Table XXX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Dewpoint - Hygrothermograph Next to Study Stack - Control Bay
Temperature (°F)

Month	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	S_x	$\bar{x}$	N
Apr			17	48	17	13	5					5 3	39.8	521
May				1	14	44	34	7				4.0	49 5	744
Jun						1	26	26	37	8	2	5 1	59.5	720
Jul							-	1	18	61	19	2 8	68 0	744
Aug								5	25	59	10	3.3	66.5	744
Sep					1	4	33	19	18	18	6	7 0	59.3	720
Oct					5	25	36	27	6			4.6	53.1	732
Nov	1	20	9	24	16	11	10	8	1			9 6	40.5	720
Dec		7	7	21	29	26	8	1				6.4	42.4	648

Table XXXI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1956
Low Level Warehouse Dewpoint - Hygrothermograph in Southeast Corner of Bay
Temperature (^{o}F)

Month	14-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	S_x	$\bar{x}$	N
Apr				46	33	12	8	1				4.4	37.5	637
May					1	26	52	18	2			4.0	49.5	744
Jun							4	29	45	21	5	3.8	57.2	720
Jul									10	85	8	1.8	62.3	744
Aug									31	59		2.5	61.4	744
Sep					1	4	23	29	17	10	15	7.0	55.4	695
Oct				1	6	19	26	41	5			5.3	48.8	720
Nov	1	10	20	16	20	15	5	8	2			9.3	36.5	678
Dec		2	10	9	28	47	1					5.5	38.6	616

Table XXXII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Bottom Carton Air Temperature - Ventilated Bay
Temperature (°F)

Month	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	S_x	$\bar{x}$	N
Feb			11	30	37	19	2															1 9	45.9	672
Mar				5	26	14	51	4														2.0	49.0	744
Apr							10	32	20	6	4	0	10	18	0	0						5 0	56.2	689
May											1	15	8	14	21	36	4					3 1	65.8	744
June															6	33	7	8	33	14		3 3	72.0	720
July																		3	48	38	10	1.3	75.6	744
Aug																	2	17	32	30	18	2.1	75 4	744
Sep															7	5	2	6	32	45	3	2.8	74.6	720
Oct								7	7	7	18	18	12	20	9							3.9	60 5	743
Nov					1	14	15	22	21	25	1											2.8	53.1	720
Dec	2	6	7	18	21	27	20															3.0	46.7	744

Table XXXIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Top Carton Air Temperature - Control Bay
Temperature (°F)

Month	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	84 -5	86 -7	88 -9	s_x	$\bar{x}$	N
Feb		5	26	34	17	10	4	3																		2.7	47.0	672
Mar				2	25	11	22	22	11	7																3 2	52.5	744
Apr								4	27	24	5	4	3	5	3	1	5	10	7							7 5	62.8	689
May														6	9	6	19	22	18	18	2					3 5	74 1	744
Jun																4	15	16	6	2	4	20	23	10		5.2	79.7	720
Jul																					20	38	34	7		1.7	83.1	744
Aug																	2	11	16	7	13	24	13	12	2	4 0	80 7	744
Sep															7	3	2	2	19	29	25	14				3 6	78.1	720
Oct								5	8	5	6	26	22	19	9											3 7	63 0	743
Nov						12	19	15	23	26	4	1														3 0	55.5	720
Dec	4	7	3	18	22	25	20	1																		3.3	48 6	744

Table XXXIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Air Temperature Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	32 -3	34 -5	36 -7	38 -9	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	S_x	$\bar{x}$	N
Feb				1	10	15	18	30	20	7																	2.8	45.6	672
Mar						3	7	20	16	32	21	1															2.7	49.2	744
Apr								1	3	7	17	27	7	5	4	2	10	13	3								5.8	57.4	689
May													2	4	8	5	10	16	23	22	6	1					4.0	66.7	744
Jun																		6	12	20	5	11	37	9			3.7	73.5	720
Jul																					3	22	35	29	9	1	1 9	77.0	744
Aug																			1	5	17	20	21	24	12		2.9	76.0	744
Sep																	5	7	2	3	5	24	34	18	1		4 1	74.5	720
Oct									2	2	6	11	11	11	16	18	12	8	1								4.6	59 6	743
Nov						2	5	4	2	15	14	15	23	8	1												4 2	52.6	720
Dec	1	1	1	4	5	13	14	21	16	13	9	1															4.3	46.2	744

Table XXXV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
High Level Warehouse Air Temperature Next to Study Stack - Control Bay
Temperature (°F)

Month	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	S_x	$\bar{x}$	N
Feb		27	47	15	8	2								4.7	47.5	672
Mar			25	38	22	9	4							5.3	53.5	744
Apr				9	24	19	16	14	7	6	2	1		9.3	65.5	689
May						6	10	31	25	16	8	2		6 8	75.4	744
Jun							5	19	15	25	18	11	5	7.7	81 6	720
Jul									22	31	21	21	4	5.8	84.7	744
Aug							1	16	26	25	18	10	3	6 5	81 5	744
Sep							11	11	40	22	12	2		6.1	77 7	720
Oct				6	23	29	32	7	2					5.4	62.7	743
Nov			8	28	39	18	5							4 9	56 1	720
Dec	3	14	34	35	11	2								5.0	49 3	744

Table XXXVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Intake Air Temperature - Low Level Ventilated Bay
Temperature (^{o}F)

Month	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	S_x	$\bar{x}$	N
Feb		1	7	14	11	21	38	6								7.1	41 4	672
Mar				6	8	17	33	32	1							6.1	46.2	743
Apr				1	2	2	7	33	21	9	20	3				7.6	56.6	688
May						1	2	4	9	21	39	20	1			6.4	64 7	744
Jun									3	5	19	29	37	5		5.3	72.5	720
Jul										3	10	22	48	15	1	4.8	75.2	744
Aug									1	8	18	28	27	15	1	6 0	73.0	744
Sep							1	3	7	8	16	32	31	2		7 2	70.4	720
Oct				1	3	7	15	19	27	23	4					7.4	54 2	742
Nov			2	7	6	13	20	27	23	2						7.9	48.1	720
Dec	2	1	1	12	18	25	25	14								7.6	41.6	744

Table XXXVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Exhaust Air Temperature
Temperature (°F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	100-4	105-9	110-4	S_x	$\bar{x}$	N
Feb		4	29	39	12	7	5	1	1									6.6	47 8	672
Mar			7	32	27	12	8	7	4	2								8.2	53.3	744
Apr				4	16	17	19	11	13	6	4	3	2	2	1			12 3	65.0	689
May						6	7	15	28	17	7	6	6	4	1			10.4	74 9	744
Jun								6	16	26	21	9	8	5	4	3	1	10.1	82 1	720
Jul									7	28	27	10	6	9	9	2		9 2	84 6	744
Aug								1	15	31	24	10	6	4	5	1		8.4	81.8	744
Sep							6	9	6	35	25	9	5	3				7.6	78.4	720
Oct				3	16	21	33	14	6	4	1							7 1	61 0	743
Nov			8	19	25	30	11	4	2									6 7	53.9	720
Dec	2	7	27	29	23	7	4											6 3	47.1	744

Table XXXVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Top Carton Air Temperature - Ventilated Bay
Temperature (^{o}F)

Month	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	S_x	$\bar{x}$	N
Feb		14	28	30	25	3																	2 1	45.9	672
Mar			3	28	7	41	17	4															2.5	49.7	744
Apr						1	20	33	9	6	8	2	0	5	10	6							6.0	58 1	689
May												13	7	9	12	25	29	4	1				3.6	69.2	744
Jun																15	25	3	5	22	29		3.9	76 0	720
Jul																			10	42	39	9	1 5	79 4	744
Aug																	1	15	22	18	31	12	2.6	78 5	744
Sep															8	2	3	4	18	45	20		3.2	77.2	720
Oct							4	9	5	15	23	11	17	15									3 9	60.9	743
Nov					10	18	20	22	28	1													2.7	53.4	720
Dec	8	5	16	21	27	22																	3.0	46.9	744

Table XXXIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Outside Air Temperature - Richmond Depot
Temperature (^{o}F)

Month	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90 4	95-9	S_x	$\bar{x}$	N
Feb			2	7	16	20	19	9	7	9	5	2	1						10.7	42.4	668
Mar					7	13	20	22	11	12	5	4	3						10 1	47.8	744
Apr					3	5	3	6	9	14	12	15	14	9	4	3	1		13.6	61 8	686
May							2	3	4	9	13	22	20	10	7	7	1		10 7	68.4	738
Jun										5	5	15	23	19	12	12	8	1	9 1	75.8	719
Jul										1	5	11	18	18	21	14	8	3	8.8	78 2	744
Aug										3	12	18	20	17	13	7	5	2	9.4	74.2	744
Sep								2	5	9	6	19	25	16	9	8			9.5	70.6	720
Oct					2	6	9	14	16	18	22	8	5	1					9.7	54.5	741
Nov			2	3	7	7	13	15	13	18	9	6	4						11 8	49 7	715
Dec	1	2	1	4	15	17	15	13	14	7	5	3							11.3	42.5	744

Table XL

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Bottom Carton Air Temperature - Control Bay
Temperature (°F)

Month	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	84 -5	S_x	$\bar{x}$	N
Feb			22	54	20	4																		1.4	46.6	672
Mar				3	32	16	44	5																2 0	50 8	744
Apr							9	29	20	4	7	7	2	3	10	8	1							5.9	59 2	689
May												5	10	7	21	21	24	12	1					3.3	69.8	744
Jun															6	23	9	3	13	29	14	2		4.1	75.4	720
Jul																		3	18	39	28	11	1	1.9	79.1	744
Aug																2	10	16	15	19	21	13	4	3.4	78.0	744
Sep															10	3	3	19	40	24	2			3.0	75.6	720
Oct								4	10	6	10	24	20	23	3									3.5	62.7	743
Nov						10	18	19	19	29	5													2.8	55.5	720
Dec	1	6	6	15	23	27	21																	3.0	48.8	744

Table XLI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
High Level Warehouse Temperature Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	S_x	$\bar{x}$	N
Feb		1	30	55	13									2.6	46.0	672
Mar			4	36	48	11								3.4	50.3	744
Apr				4	22	34	7	13	14	4	1			8.1	60 3	689
May						6	11	24	39	18	1			5.4	69.9	744
Jun								5	22	34	29	9		5.0	77.6	720
Jul									4	42	43	10		3.5	80 1	744
Aug								1	15	34	33	15	1	4.6	79.5	744
Sep							4	11	6	43	26	9		5.9	77.1	720
Oct				2	15	24	41	15	2					5.0	59 7	743
Nov				18	32	37	5							4.8	52 7	720
Dec	2	6	25	40	23	2								4 8	46 1	744

Table XLII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Air Temperature Next to Study Stack
Temperature (°F)

Month	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	86-7	S_x	$\bar{x}$	N
Feb		2	11	18	23	24	17	9	3	1																	3 2	45 2	672
Mar					7	17	16	17	23	12	8																3.4	50 5	744
Apr							1	5	7	20	22	6	4	7	5	1	6	9	6								6 6	59.7	689
May													2	5	7	6	13	20	18	19	8						4 0	70.6	744
Jun																1	5	10	17	6	5	17	25	11	2		4.5	76.7	720
Jul																				3	12	21	32	19	11	2	2.6	80 4	744
Aug																	1	3	9	12	13	14	18	15	10	3	4 2	78 7	744
Sep															5	6	3	3	3	13	24	20	13	9	1		4.9	76 1	720
Oct							1	2	3	8	13	7	11	18	21	9	3	2									4.7	61 0	743
Nov					4	5	5	17	13	14	17	18	5	1	1												4.4	54 0	720
Dec	2	4	3	10	16	18	17	12	13	3																	4.2	47.0	744

Table XLIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Warehouse Floor Surface Temperature - Ventilated Bay
Temperature (^{o}F)

Month	34 -5	36 -7	38 -9	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	S_x	$\bar{x}$	N
Feb				6	16	16	29	27	7															2.6	46 0	672
Mar						2	13	23	29	30	2													2.2	50.0	744
Apr								1	5	20	33	6	6	1	8	14	1	1	1					6.2	57.4	689
May													3	10	8	17	21	36	4					3.1	65 8	744
Jun																	8	31	7	8	45	1		3 1	71 6	720
Jul																				3	55	36	5	1 2	75.4	744
Aug																			4	18	30	34	12	2 1	75.1	744
Sep																2	8	4	3	4	37	41	1	3 2	74 0	720
Oct								1	2	4	9	12	9	18	18	14	11	1						4.3	60 5	743
Nov						2	6	5	16	18	14	23	15											3.7	53.6	720
Dec	1	1	1	4	7	16	17	22	16	13														3 8	47.2	744

Table XLIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Air Temperature - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (°F)

Month	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	S_x	$\bar{x}$	N
Jan						8	16	31	40	6																2.0	46.9	576
Feb				3	9	15	16	10	29	17																3.5	46.1	672
Mar						3	9	22	13	29	21	2														2.9	49.0	720
Apr									1	4	17	24	14	3	4	8	8	10	5							5.5	58.1	720
May													1	4	6	7	8	18	28	21	2	0	1	1	2	4.2	67.2	744
Jun																		3	9	22	7	16	34	9		3.4	73.7	718
Jul																				1	1	23	34	30	11	2.0	77.0	739
Aug																				1	9	29	32	23	6	2.2	76.2	744
Sep																6	5	3	3	3	5	14	37	22	3	4.8	74.5	720
Oct										2	7	12	7	15	22	19	12	2								3.9	59.4	547
Nov[a]																												
Dec	2	1	1	4	9	14	17	18	13	13	5	2	1													4.6	45.6	617

[a] Data missing

Table XLV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack
Temperature (^{o}F)

Month	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	S_x	$\bar{x}$	N
Jan			7	18	32	21	17	3					6 1	53 6	576
Feb				2	26	16	29	26					5.8	59.5	672
Mar					7	27	8	35	17	5			7 0	64 3	720
Apr					5	18	27	35	14				5 2	63.7	720
May			2	12	7	3	33	25	12	4			8 2	61.5	744
Jun						0	15	42	34	6	1		4 1	68 7	718
Jul					5	30	35	14	11	4			6.0	62.4	739
Aug				1	11	18	38	20	9	1			5.6	62.0	744
Sep		1	2	6	6	4	8	21	39	11	1		9 4	66 4	720
Oct				2	23	20	27	20	4	3			6 8	60.3	744
Nov[a]															
Dec	1	0	8	9	14	18	13	17	11	4	1	1	10 7	59.0	637

[a] Data missing.

Table XLVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Air Temperature - Hygrothermograph Next to Study Stack - Control Bay
Temperature (°F)

Month	34 -5	36 -7	38 -9	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	78 -9	80 -1	82 -3	84 -5	86 -7	88 -9	90 -1	S_x	$\bar{x}$	N
Jan	2	5	9	13	11	21	23	9	6	1																				3 9	43.9	576
Feb				3	14	14	30	16	11	5	5	1																		3.5	47.1	672
Mar					6	11	9	6	15	21	17	10	5																	4 5	50 9	708
Apr									1	5	5	20	16	9	5	2	6	5	11	8	5									6 7	62.5	720
May														3	4	4	9	10	18	18	18	8	3	0	1	1	1	1		4 9	71 3	744
Jun																	1	5	6	15	9	7	19	21	13	4				4 5	77.3	719
Jul																					1	6	14	23	24	23	8	1		2.8	81.7	739
Aug																			2	7	13	11	14	18	14	13	8	1		4 2	79 6	744
Sep														2	7	3	1	1	2	3	7	15	22	15	9	8	2			6 5	76.6	720
Oct								1	1	3	6	11	10	11	14	18	15	6	1	1										4 8	61.6	744
Nov[a]																																
Dec	1	1	6	6	14	14	16	16	10	12	2																			4.6	48 2	648

[a]Data missing

Table XLVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Relative Humidity Hygrothermograph Next to Study Stack - Control Bay
Temperature (^{o}F)

Month	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	s_x	$\bar{x}$	N
Jan			2	14	37	23	15	7	1					6.0	60.1	575
Feb			1	9	17	28	28	16	1					6 1	63.3	660
Mar				8	10	32	25	15	8					6.8	64 5	696
Apr			5	23	17	28	24	1						6 0	59.3	720
May				10	33	39	15	2						4.6	60.1	744
Jun					4	47	34	13	1					3.8	65.1	719
Jul		1	7	31	42	16	0	1	1	1				5.2	55 9	739
Aug	1	5	10	19	20	24	16	4						7 8	57.5	744
Sep		1	3	8	17	28	21	14	6					7.6	63 1	720
Oct			1	14	27	29	18	8	1					6.1	60.9	744
Nov[a]																
Dec			1	4	15	15	18	12	7	5	13	7	1	12.3	70.7	648

[a]Data missing.

Table XLVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay[a]
Temperature (°F)

Month	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	76-7	78-9	80-1	82-3	84-5	86-7	S_x	$\bar{x}$	N
Jan			2	14	36	27	20	2																			2 1	45 6	576
Feb	4	15	21	16	16	23	5																				3 3	42 8	562
Mar			4	15	18	13	37	12																			2 8	46.5	720
Apr							1	13	18	7	10	5	8	10	6	6	7	7	2								6 8	59 0	708
May													2	3	5	10	17	24	21	12	4						3 5	70 2	744
Jun																2	5	13	12	10	22	19	13	2			3 9	75 4	719
Jul																			1	4	11	25	25	21	11	2	2 8	80 2	593
Aug																			5	8	12	16	23	17	11	8	3 6	80 1	432
Sep-Nov[b]																													

Temperature (°F)

Month	35-9	40-4	45-9	50-4	55-9	60-4	S_x	$\bar{x}$	N
Dec	4	13	38	36	8	1	4.7	48.5	648

[a]Moved 8 April 1957 from southeast corner of ventilated bay to "C" bay
[b]Data missing.

Table XLIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Relative Humidity - Hygrothermograph in C Bay
Temperature (°F)

Month	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	s_x	$\bar{x}$	N
Jan			8	24	38	27	2						4 6	51 5	575
Feb				2	27	22	43	6					4 8	57.9	648
Mar					7	27	49	12	4				4.2	60 7	720
Apr				11	25	18	17	16	11	1			7 9	58.9	720
May	1	16	5	4	4	19	27	16	10				11 4	56.6	739
Jun						1	15	42	32	7			4 2	68.4	719
Jul			4	17	30	30	18						5 4	54.2	740
Aug	1	9	10	9	16	24	20	6	2				9 3	53.5	743
Sep			1	3	7	15	22	24	15	5	3	2	8.6	64.6	720
Oct		1	6	16	23	32	14	7					6.7	54.8	742
Nov[a]															
Dec	1	4	9	17	10	13	15	13	10	1	3		11.6	57.2	644

[a]Data missing.

Table L

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
USWB Dewpoint - Byrd Field
Temperature (°F)

Month	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	S_x	$\bar{x}$	N
Feb			1	8	13	9	25	18	8	3	6	5	1				11.1	35.1	672
Mar				3	12	18	17	25	14	6	2	1	1				8 7	34 7	744
Apr					2	11	11	7	8	8	12	20	15	5			12 9	48.4	720
May						1	3	9	4	7	16	14	27	15	1		10 8	55 8	744
Jun											3	12	21	43	19	1	5 1	66 3	720
Jul									1	3	11	18	24	30	12		6.5	63 0	744
Aug										2	9	18	37	24	9		5 8	62.9	744
Sep									3	5	9	7	11	34	27		9.6	64.0	720
Oct					1	5	8	17	17	17	19	11	4				9 2	45 5	744
Nov			1	4	5	7	15	14	10	12	11	12	4	1			12.5	42 1	720
Dec	2	2	1	2	10	16	22	17	9	6	6	3	1				11 6	34.6	744

Table LI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
USWB Air Temperature - Byrd Field
Temperature (°F)

Month	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	S_x	$\bar{x}$	N
Jan	1		2	6	7	13	18	17	19	6	2									11 8	35.7	743
Feb				2	9	17	23	17	9	6	9	5	2							10.5	42.6	672
Mar					2	7	19	22	17	12	9	4	4	2						9 7	47.0	744
Apr						2	6	4	8	10	16	13	13	11	7	4	2	1		13.4	61.8	720
May							1	2	3	6	11	16	23	16	9	6	6			10.7	67 8	744
Jun											5	6	20	22	15	12	14	5		9 2	75 7	720
Jul											1	6	14	18	19	17	15	8	1	8 8	78 4	744
Aug											4	15	21	18	17	12	6	5		8.9	74.0	744
Sep								1	3	6	7	6	19	25	14	10	15	1		10 3	71.0	720
Oct						2	6	9	15	21	17	17	7	3						9 2	54.5	744
Nov				1	3	6	9	14	15	16	16	11	5	2						11.0	50.2	720
Dec		1	2	2	4	14	20	15	14	13	7	4	1							10 9	42.9	744

Table LII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Dewpoint Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	s_x	$\bar{x}$	N
Jan			12	24	47	15								4 1	31.1	576
Feb			9	28	18	42	1							5.1	32.9	672
Mar				6	27	37	29							4 2	37 4	720
Apr					5	19	34	9	20	12				7.0	45.7	720
May						10	10	4	27	43	1	1	2	7 5	53.2	744
Jun									1	24	57	18		3 1	62.6	718
Jul									2	21	55	22		3.2	62 9	739
Aug									3	30	49	17		3 4	61 9	744
Sep						1	5	6	11	1	24	49	1	8 0	62.2	720
Oct					3	17	23	34	18	4				5 6	46.0	547
Nov[a]																
Dec	2	5	5	27	31	13	12	2	1					7.3	32.0	606

[a] Data missing

Table LIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Dewpoint Hygrothermograph Next to Study Stack - Control Bay
Temperature (°F)

Month	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	S_x	$\bar{x}$	N
Jan	16	28	33	17	4								5.3	31 1	575
Feb		16	35	38	10	1							4 3	35.2	660
Mar			10	58	30								3 2	39.2	684
Apr			1	20	34	6	10	20	7				8 3	47 9	720
May						15	25	39	16	1	0	1	5 4	56 6	744
Jun							2	15	32	47	4		4.1	64.5	719
Jul								9	58	30	1		2.8	64.2	739
Aug							3	16	60	18	2		3 5	62.8	744
Sep				1	3	6	9	5	24	47	4		7.5	62.8	720
Oct				7	28	30	29	4					5.2	47.8	744
Nov[a]															
Dec	4	6	21	22	32	14	1						6.3	38.8	648

[a] Data missing

Table LIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1957
Low Level Warehouse Dewpoint - Hygrothermograph in C Bay
Temperature (^{o}F)

Month	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	s_x	$\bar{x}$	N
Jan			15	48	37									3.1	29.0	575
Feb			28	30	36	6								4.4	29 1	562
Mar			1	16	53	30								3.1	33 7	720
Apr					10	29	19	12	24	5				7.2	44.4	708
May						12	10	3	20	36	18			8.2	53.5	739
Jun									1	16	41	41		3.6	64.0	719
Jul									6	31	46	16		3.8	61 7	593
Aug								4	12	28	45	8	1	4.8	60.2	431
Sep-Nov[a]																
Dec	1	6	5	19	23	25	13	5	1					8 2	34.0	644

[a]Data missing.

Table LV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Bottom Carton Air Temperature - Ventilated Bay
Temperature (°F)

Month	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	S_x	$\bar{x}$	N
Jan	1	6	21	20	39	11	2	1									2.4	39 2	720
Feb	1	12	29	21	18	13	3										2.9	38.3	672
Mar						26	55	19									1.2	44 4	746
Apr								9	20	18	6	6	6	22	11		4.8	53 4	693
May													3	47	45	5	1 2	59 6	358

Table LVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Top Carton Air Temperature - Control Bay
Temperature (^{o}F)

Month	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	S_x	$\bar{x}$	N
Jan		3	26	25	26	17	3													2.4	41.2	720
Feb	4	14	25	23	12	9	10	4												3 6	40.8	672
Mar						20	33	31	15											1.9	47 4	746
Apr								2	7	21	12	4	7	4	3	12	22	6		6 3	59.2	694
May														1	19	41	11	23	5	2.4	65 4	358

Table LVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	26-7	28-9	30-1	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	S_x	$\bar{x}$	N
Jan	1	1	3	5	8	14	22	22	20	3	1										3 7	38 6	720
Feb		2	4	10	11	22	18	8	10	10	3										4.3	37.9	672
Mar							1	7	25	35	31	1									1 9	44 3	746
Apr										1	5	17	19	7	6	4	10	22	8		5 4	54.5	694
May															3	9	23	36	23	7	2.2	60 3	358

Table LVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
High Level Warehouse Air Temperature Next to Study Stack - Control Bay
Temperature (^{o}F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	s_x	$\bar{x}$	N
Jan	3	26	43	24	4								4.1	42.1	720
Feb	8	33	31	20	2	2	1						5.8	41 6	671
Mar			21	53	17	8	1						4.1	48 0	746
Apr				4	22	14	19	22	12	6	1		8.1	61 9	694
May						6	35	31	14	6	5	1	6 4	67.2	358

Table LIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Intake Air Temperature - Low Level
Temperature (°F)

Month	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	S_x	$\bar{x}$	N
Jan	2	4	8	10	20	29	24	1						7.6	33 7	720
Feb	1	2	6	16	24	26	18	5						7.3	34.1	672
Mar				1	6	22	37	31	1					4.5	41.8	746
Apr						2	7	17	25	23	24	1		6.6	54 0	694
May								1	15	32	43	9	1	4.2	59 2	358

Table LX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Exhaust Air Temperature
Temperature (°F)

Month	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	90-4	95-9	100-4	S_x	$\bar{x}$	N
Jan	4	14	36	27	12	5	1										5 8	39 5	720
Feb	1	20	34	19	14	5	2	2	1								7.8	40.5	672
Mar			1	44	37	8	4	3	1								5 9	46.5	746
Apr				1	17	14	14	18	13	8	6	4	2	1			11.1	61 4	694
May						1	21	30	17	10	5	5	3	3	3	1	10 9	67.6	358

Table LXI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Top Carton Air Temperature - Ventilated Bay
Temperature (°F)

Month	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	S_x	$\bar{x}$	N
Jan		5	22	24	35	11	3											2 8	39 3	720
Feb	1	13	32	17	16	13	7	1										3.0	38.7	670
Mar						11	48	40										1.2	45 0	746
Apr								5	12	26	5	8	3	4	18	18		5 6	55 0	694
May														4	46	41	8	1 4	61 6	358

Table LXII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Outside Air Temperature - Richmond Depot
Temperature (°F)

Month	5-9	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	s_x	$\bar{x}$	N
Jan	1	2	6	8	13	21	17	14	9	5	1							10 5	33.7	720
Feb	1	4	9	7	13	19	14	13	10	4	1							12 4	34 5	669
Mar					2	10	21	26	24	8	6	1						7.3	42 9	741
Apr							2	8	12	13	18	15	11	9	5	3	2	11 5	58.6	693
May									4	17	19	18	14	13	7	3	3	9 8	63 2	358

Table LXIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay
Temperature (°F)

Month	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	S_x	$\bar{x}$	N
Jan		1	20	27	29	21	2	1											2.3	41.7	720
Feb	1	11	21	32	13	16	5	1											2.9	40.9	672
Mar						18	46	33	3										1.5	46.9	746
Apr								5	15	20	7	7	4	4	23	14			5.5	57.0	694
May														13	44	28	13	2	1.9	63.3	358

Table LXIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay
Temperature (^{o}F)

Month	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	S_x	$\bar{x}$	N
Jan	3	14	39	40	4						4.2	38 5	720
Feb	1	19	43	20	13	2					5 0	38.5	672
Mar			1	44	53	2					2 4	44 9	746
Apr					16	27	16	31	9		6 2	56 4	694
May							20	58	16	5	3 7	62 2	358

Table LXV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature Next to Study Stack - Control Bay
Temperature (^{o}F)

Month	30-1	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	S_x	$\bar{x}$	N
Jan		4	7	15	22	21	15	14	1													3.6	39.6	720
Feb	3	8	11	18	21	14	5	11	7	3												4.5	39.0	672
Mar							20	28	29	20	3											2.2	45.7	746
Apr									3	6	18	12	7	5	5	6	15	16	7			6.2	57.3	694
May														1	8	15	28	22	13	11	2	3.0	63.6	358

Table LXVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Warehouse Floor Surface Temperature
Temperature (°F)

Month	28-9	30-1	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	S_x	x	N
Jan	1	1	3	5	10	22	26	27	1	2									3 3	39 8	720
Feb	2	2	10	9	21	19	13	13	8	3									3.9	38 2	672
Mar							5	23	39	32	1								1 7	44.5	746
Apr									1	6	17	20	6	8	4	26	10		4 7	53 7	694
May														1	11	40	40	9	1 6	59 5	358

Table LXVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	28-9	30-1	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	S_x	$\bar{x}$	N
Jan		2	6	9	16	28	20	15	3											3.3	38.4	734
Feb	1	2	8	13	28	18	8	12	5	2	1									3.9	37.9	666
Mar							4	22	39	33	1									1.8	44.6	674
Apr									1	5	16	20	10	5	4	11	20	7	1	5.3	54.3	720
May														4	14	27	33	17	5	2.4	59.7	360

Table LXVIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	s_x	$\bar{x}$	N
Jan			6	19	28	18	11	5	4	7	1		9 6	56.1	744
Feb	14	15	22	19	14	4	7	3					9 4	45 2	657
Mar				3	14	24	28	13	10	6	1		7 4	61 8	674
Apr				1	14	11	16	28	17	9	3		8 2	64 9	720
May							1	18	11	25	44	1	5 6	76 6	359

Table LXIX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay
Temperature (^{o}F)

Month	32-3	34-5	36-7	38-9	40-1	42-3	44-5	46-7	48-9	50-1	52-3	54-5	56-7	58-9	60-1	62-3	64-5	66-7	68-9	70-1	72-3	74-5	S_x	$\bar{x}$	N
Jan		3	6	13	21	21	18	11	3	1	2												3 7	42 2	744
Feb	3	12	15	17	19	10	9	9	3	2	2												4.5	40 3	669
Mar					1	13	24	25	19	10	5	3											3 0	46.8	674
Apr								2	5	8	13	11	8	8	7	8	10	9	8	1			6 4	58 5	720
May														8	16	13	21	11	15	7	5	1	4 1	64 9	360

Table LXX

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack - Control Bay
Temperature (^oF)

Month	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	S_x	$\bar{x}$	N
Jan	1	3	10	35	28	9	7	4	6.8	60 3	744
Feb	1	5	32	29	12	15	5		6 8	57 8	672
Mar	2	8	12	35	23	13	4	1	6 7	58 7	674
Apr	1	14	30	25	18	9	1		6.2	55 8	720
May			4	14	28	39	14		5.1	64 3	360

Table LXXI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Air Temperature - Hygrothermograph in C Bay
Temperature (°F)

Month	26 -7	28 -9	30 -1	32 -3	34 -5	36 -7	38 -9	40 -1	42 -3	44 -5	46 -7	48 -9	50 -1	52 -3	54 -5	56 -7	58 -9	60 -1	62 -3	64 -5	66 -7	68 -9	70 -1	72 -3	74 -5	76 -7	S_x	$\bar{x}$	N
Jan					2	8	18	26	23	10	11	12															3 1	41.3	744
Feb	1	0	3	4	7	14	18	15	13	10	9	2	2	1													5.0	40.1	672
Mar								1	8	19	28	25	10	7	2												2 8	47.2	651
Apr											1	9	16	8	8	8	6	9	15	11	8	1					6 0	57.6	720
May																	9	16	23	16	12	9	5	4	2	1	4.3	64.5	360

Table LXXII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Relative Humidity - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	S_x	$\bar{x}$	N
Jan	1	10	29	13	7	13	18	6				9 7	50 1	744
Feb		4	16	33	16	10	9	6	3	1		8 8	51 1	672
Mar	1	5	4	9	30	13	12	12	12	1		9 9	56 6	651
Apr	1	2	4	3	8	17	20	18	14	8	4	10 6	62.4	714
May		1	3	3	10	9	16	14	38	4		9 0	64.4	357

Table LXXIII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
U. S. W. B. Dewpoint - Byrd Field
Temperature (^{o}F)

Month	-15-11	-10-6	-5-1	0-4	5-9	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	S_x	$\bar{x}$	N
Jan				1	9	13	18	14	14	12	8	5	1	1	1			11.1	24.3	744
Feb	1	1	3	4	7	16	20	7	6	14	9	5	3					13 3	21 9	663
Mar							2	14	26	26	20	7	3					6.4	32.0	745
Apr								1	9	15	16	19	11	11	9	7	1	10 6	43.4	720
May											3	8	18	17	20	27	6	7.6	55 5	735

Table LXXIV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
U. S. W. B. Air Temperature - Byrd Field
Temperature (°F)

Month	5-9	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	65-9	70-4	75-9	80-4	85-9	s_x	$\bar{x}$	N
Jan		2	7	8	15	21	18	14	9	3	1							9 7	34.4	744
Feb	1	6	8	6	20	16	15	11	8	4	1	1	2					12 2	33.8	672
Mar					3	15	27	25	18	7	3	1						6 9	42 1	745
Apr						1	3	12	12	18	15	15	9	6	4	2	1	11 1	57 4	720
May									6	9	16	19	19	13	10	5		9 6	65 5	735

Table LXXV

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Dewpoint - Hygrothermograph Next to Study Stack - Ventilated Bay
Temperature (^{o}F)

Month	0-4	5-9	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	S_x	$\bar{x}$	N
Jan			4	18	35	27	10	5	1				5 7	24.9	734
Feb	1	10	17	29	21	12	7	2					7 1	19 9	651
Mar						31	52	16					3 2	32 3	674
Apr						4	18	22	17	19	20		7 3	42.5	720
May										34	52	14	2.8	52 1	359

Table LXXVI

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Dewpoint - Hygrothermograph Next to Study Stack - Control Bay
Temperature (°F)

Month	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	S_x	$\bar{x}$	N
Jan		14	47	29	10					3 7	29 6	744
Feb	7	40	22	26	4					5 0	27 1	669
Mar		2	13	69	16					2.8	33 0	674
Apr				16	26	19	26	10	1	6 3	42 6	720
May							28	58	14	2 8	52.4	360

Table LXXVII

Percentage Frequencies, Means and Standard Deviations of Hourly Observations by Months - 1958
Low Level Warehouse Dewpoint - Hygrothermograph in C Bay
Temperature (^{o}F)

Month	5-9	10-4	15-9	20-4	25-9	30-4	35-9	40-4	45-9	50-4	55-9	60-4	S_x	$\bar{x}$	N
Jan		2	29	26	25	17	0						5 6	24.7	744
Feb	2	5	25	28	17	13	7						7 1	24 2	672
Mar				3	34	38	20	4					4.3	32.4	651
Apr					7	6	14	20	29	23			7 4	44.4	714
May								5	39	38	14	2	4.2	51.8	357

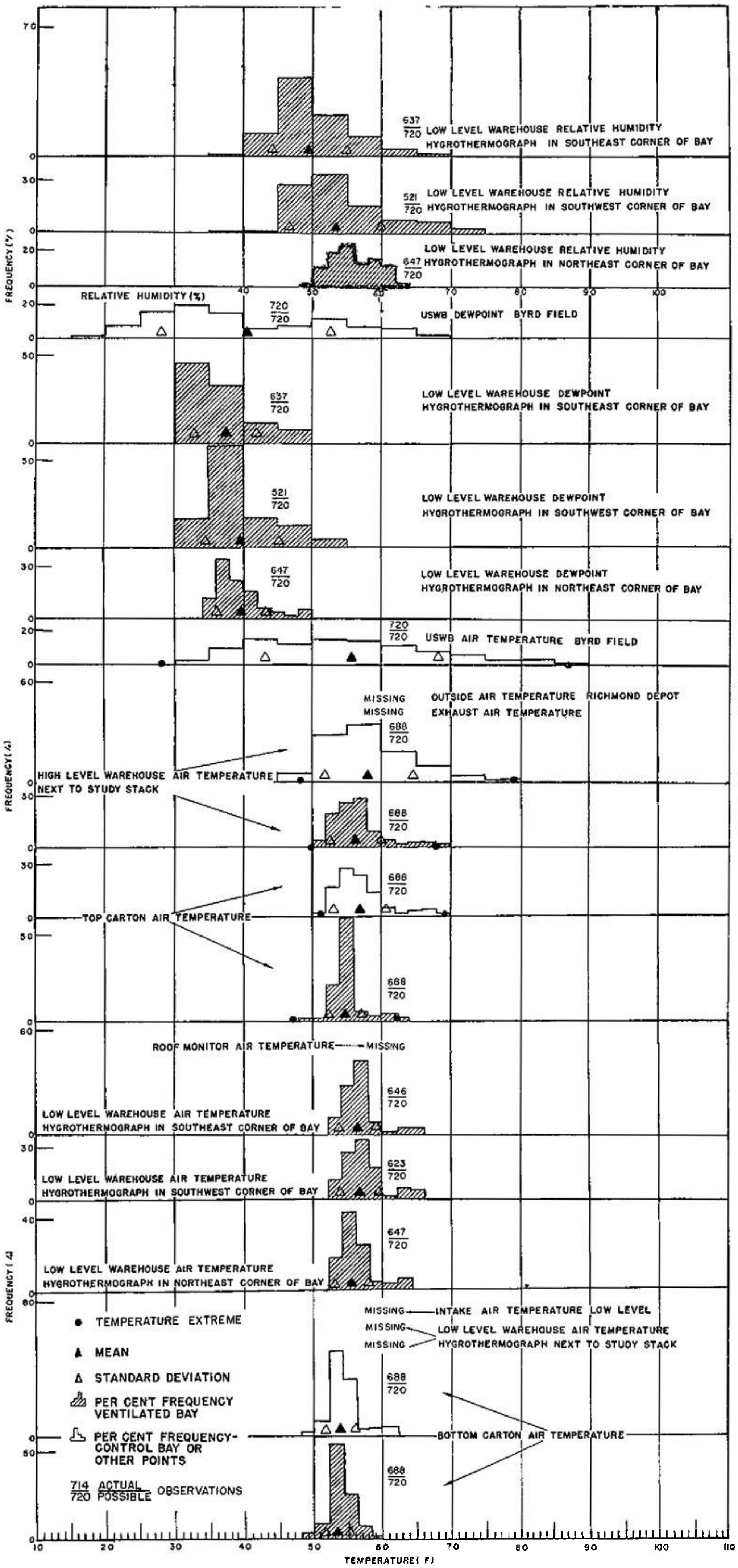

Figure 25. Frequencies, monthly means, and standard deviations of hourly observations for April, 1956

FREQUENCIES, MONTHLY MEANS, AND STANDARD DEVIATIONS OF HOURLY OBSERVATIONS MAY 1956

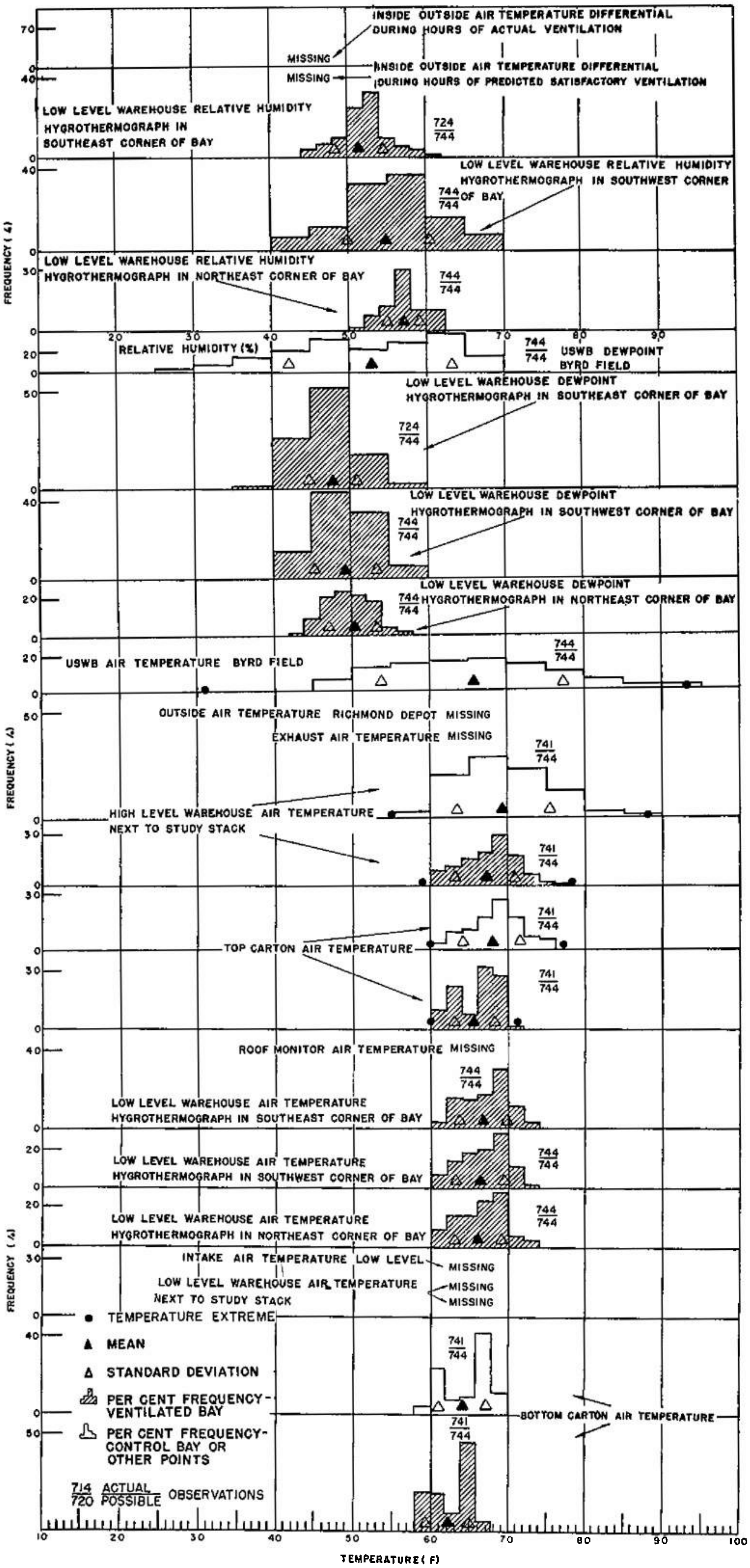

Figure 26. Frequencies, monthly means, and standard deviations of hourly observations for May, 1956

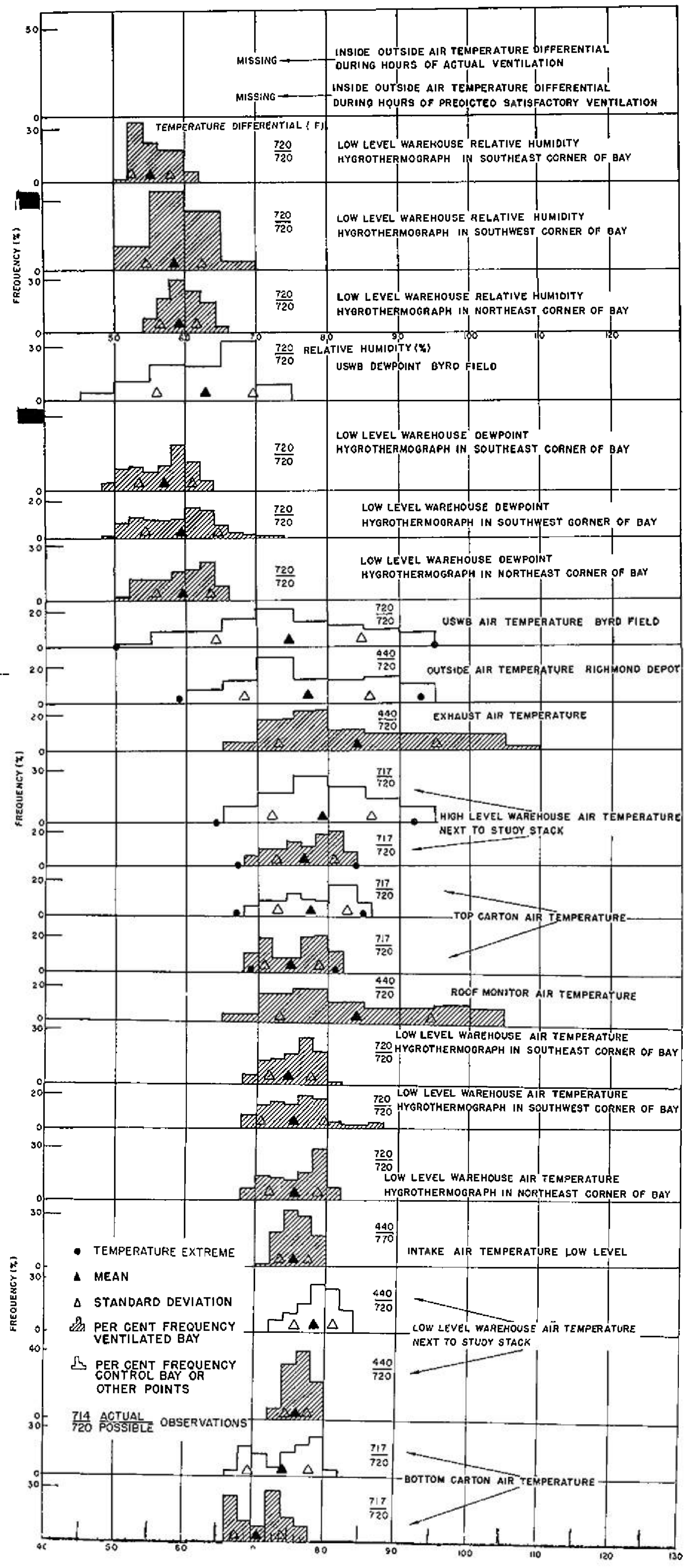

Figure 27 Frequencies, monthly means, and standard deviations of hourly observations for June, 1956

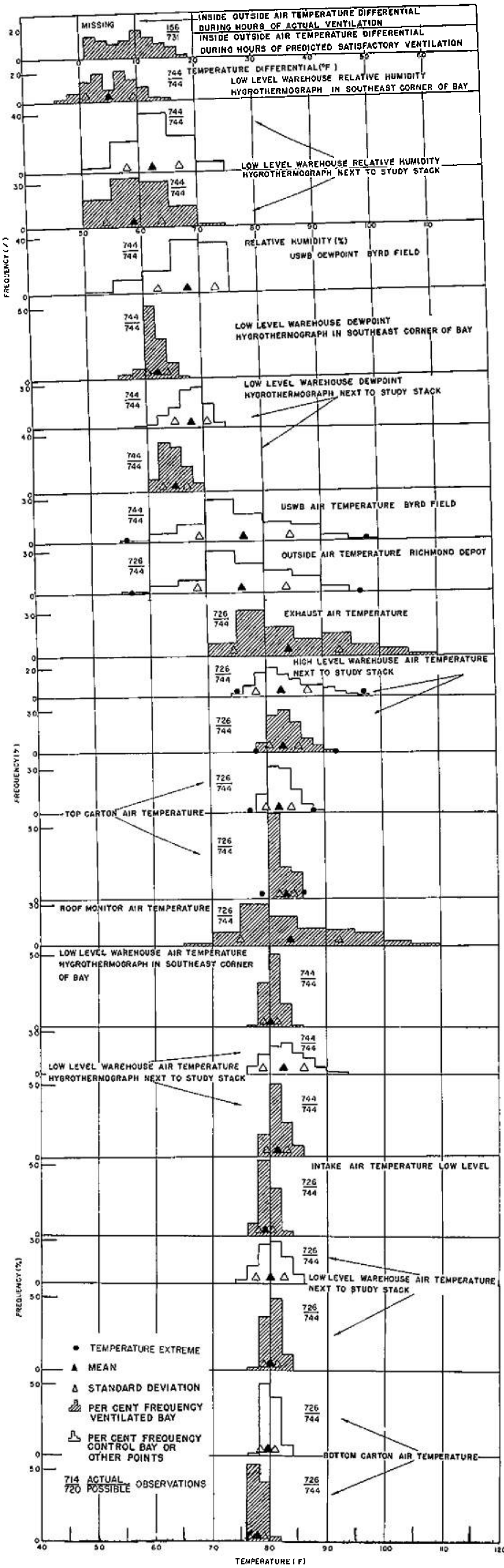

Figure 28 Frequencies, monthly means, and standard deviations of hourly observations for July, 1956

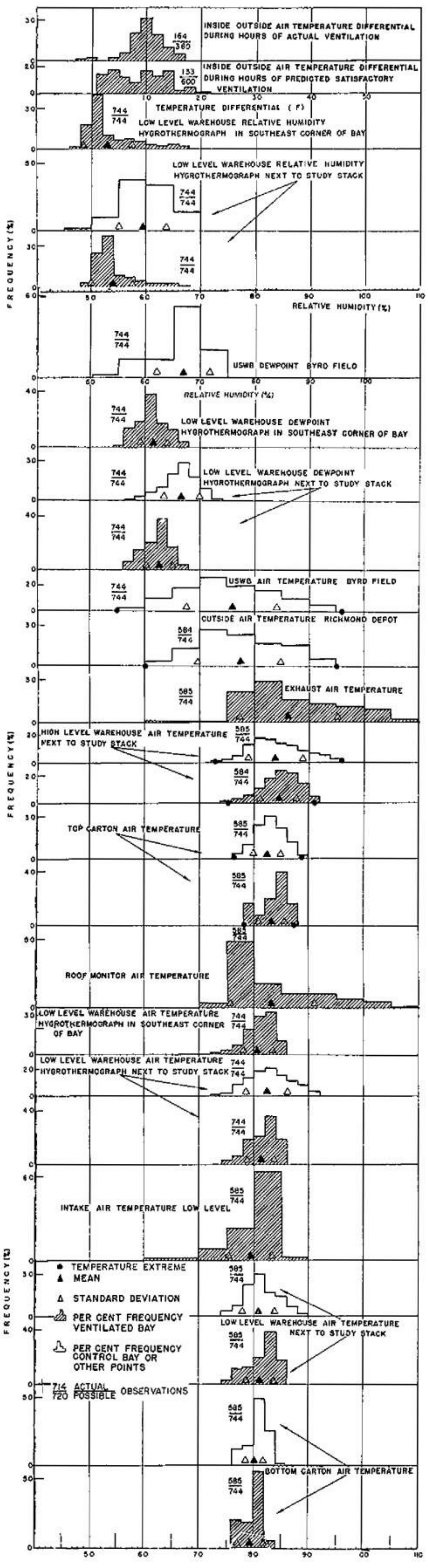

Figure 29 Frequencies, monthly means, and standard deviations

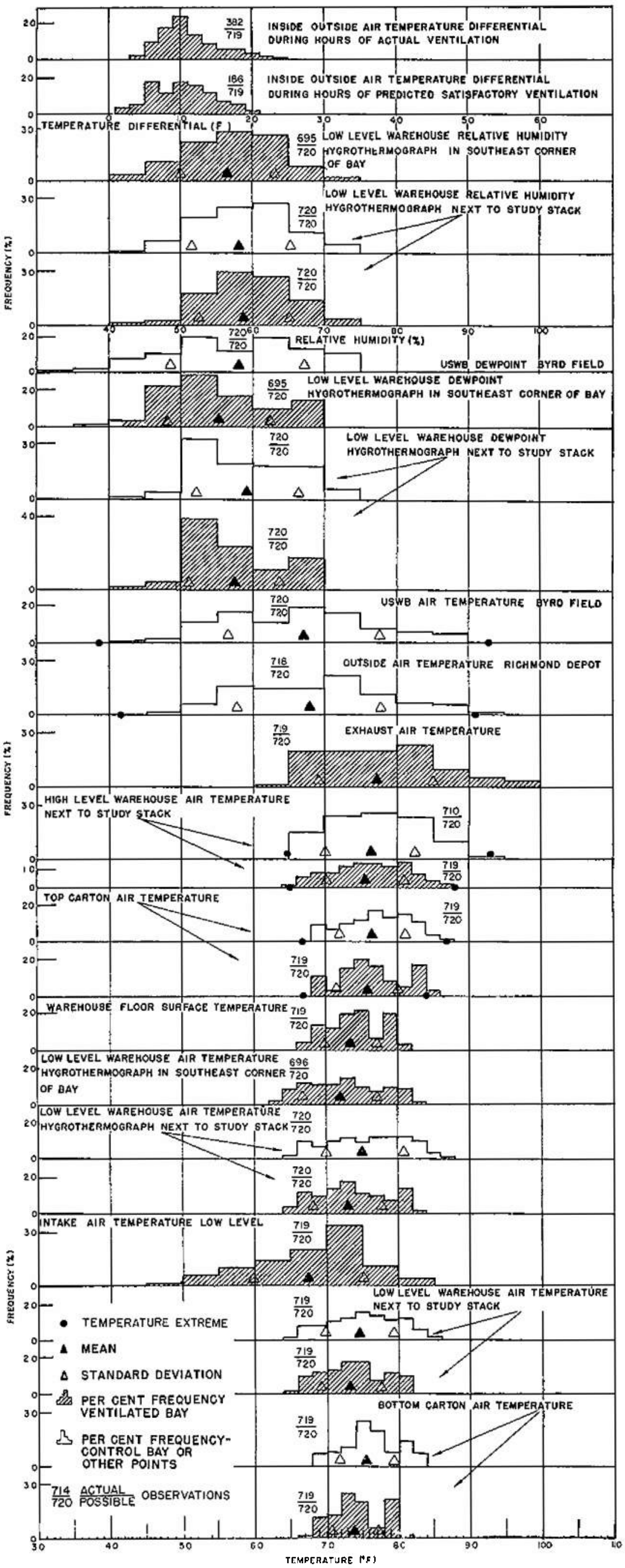

Figure 30. Frequencies, monthly means, and standard deviations of hourly observations for September, 1956.

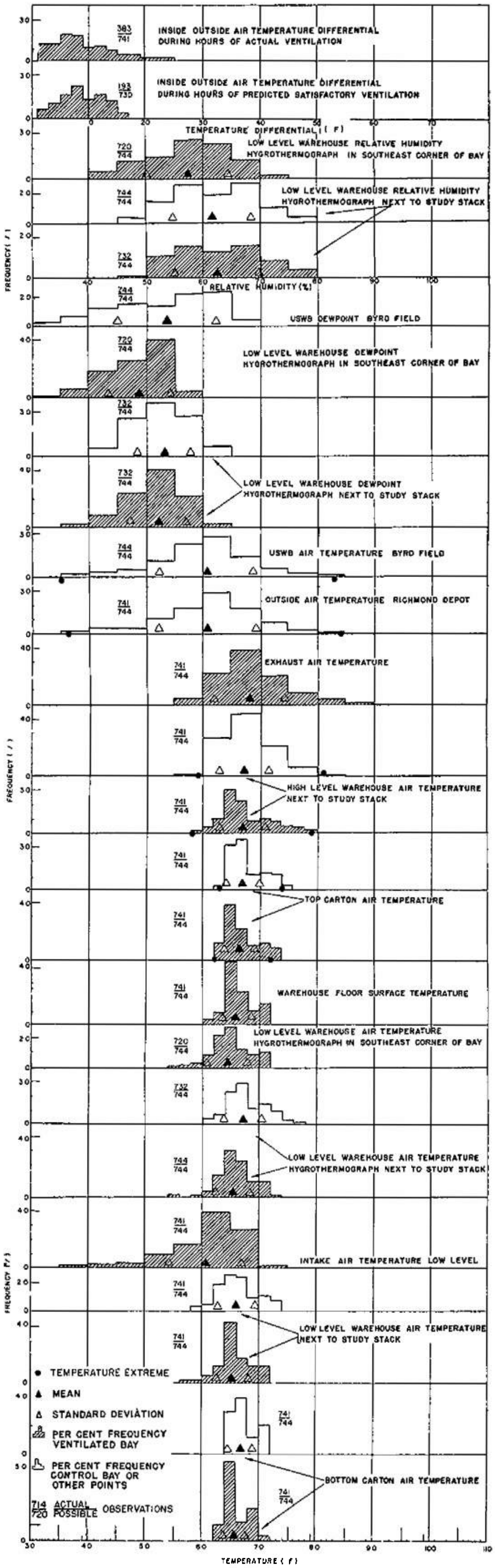

Figure 31   Frequencies, monthly means, and standard deviations of hourly observations for October, 1956

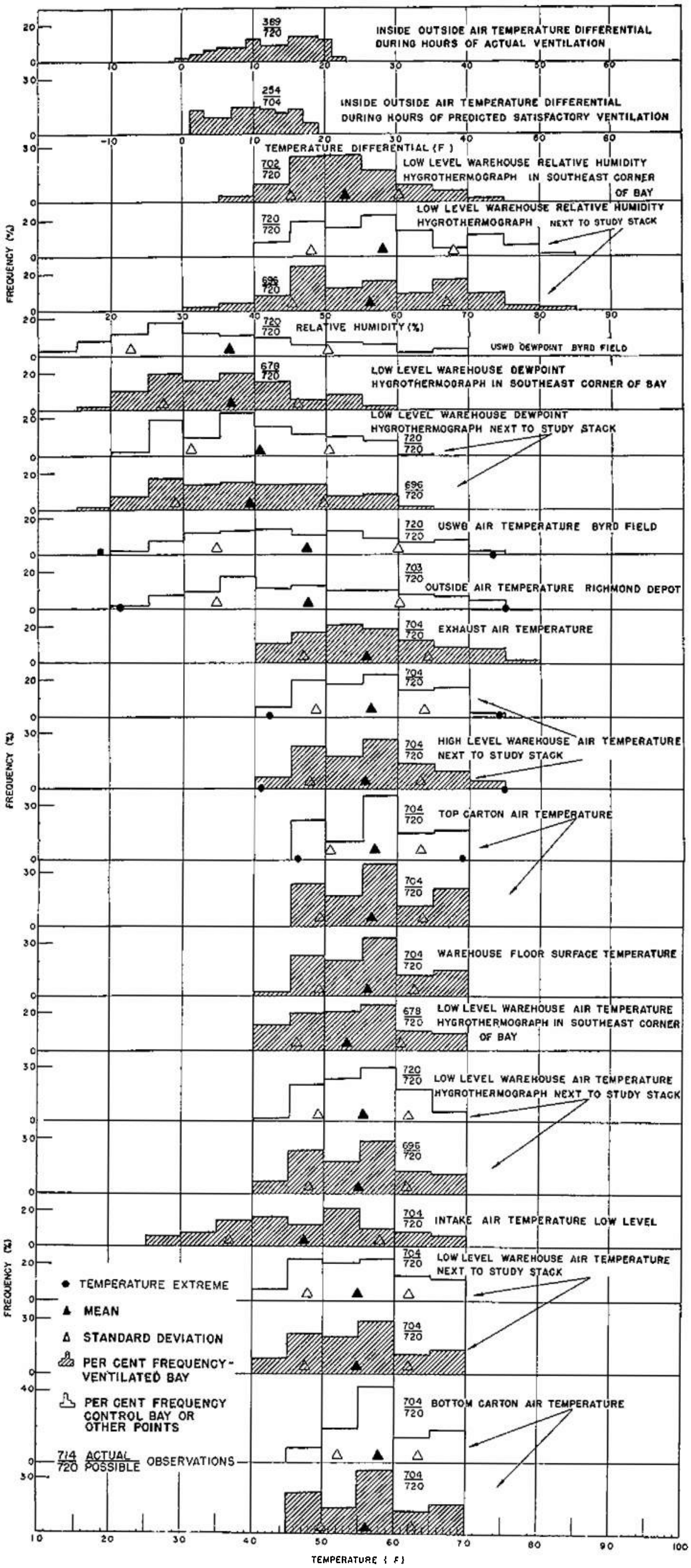

Figure 32. Frequencies, monthly means, and standard deviations of hourly observations for November, 1956.

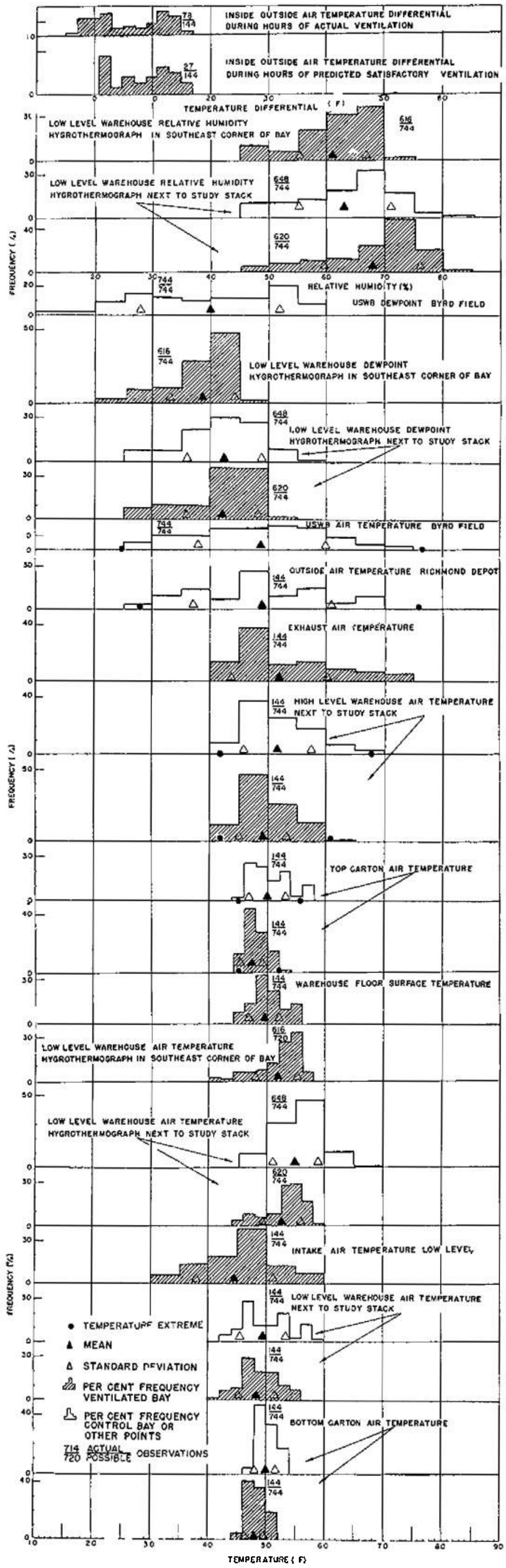

Figure 33 Frequencies, monthly means, and standard deviations of hourly observations for December, 1956

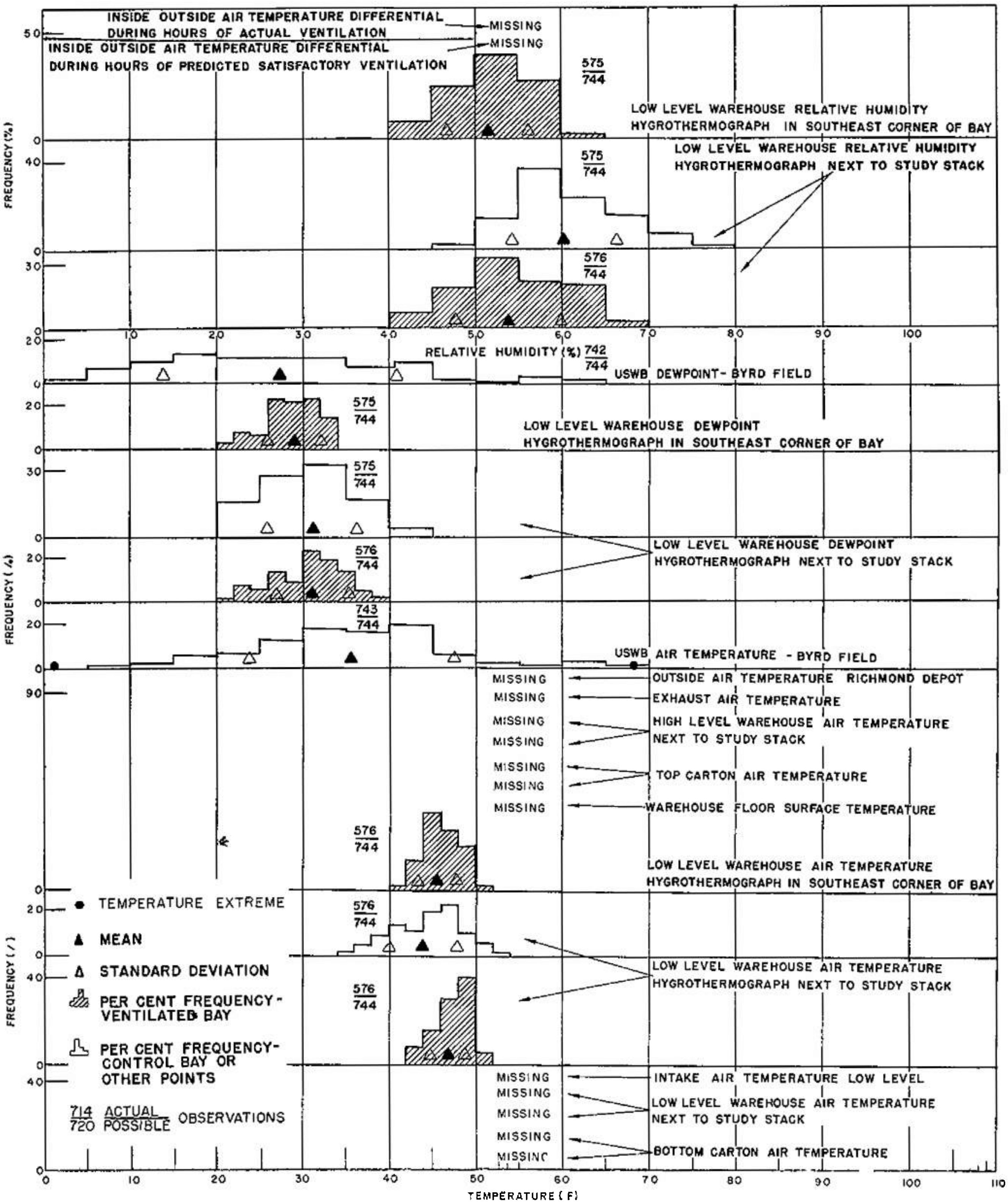

Figure 34. Frequencies, monthly means, and standard deviations of hourly observations for January, 1957.

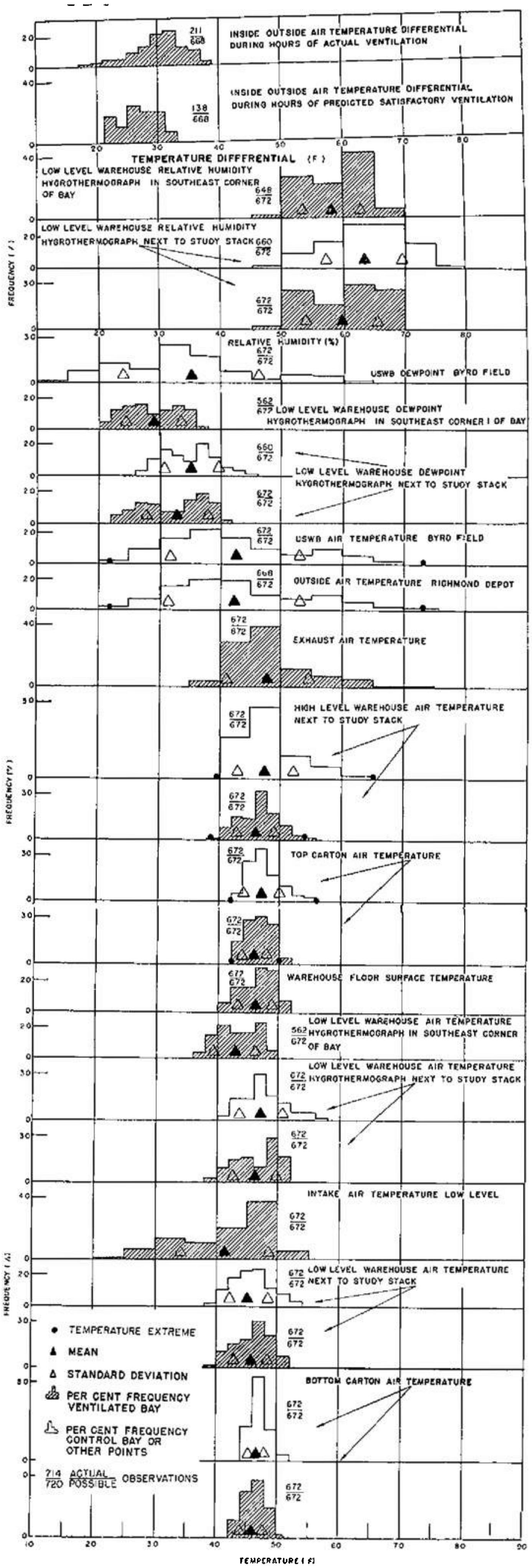

Figure 35. Frequencies, monthly means, and standard deviations of hourly observations for February, 1957

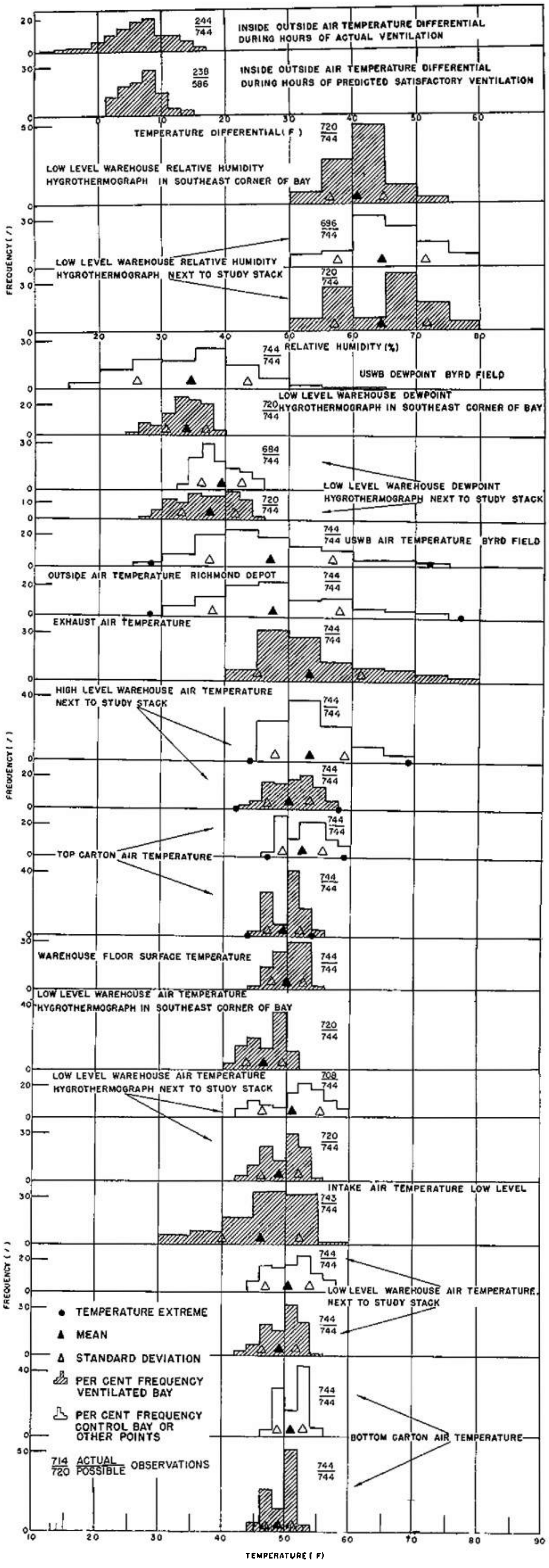

Figure 36. Frequencies, monthly means, and standard deviations of hourly observations for March, 1957

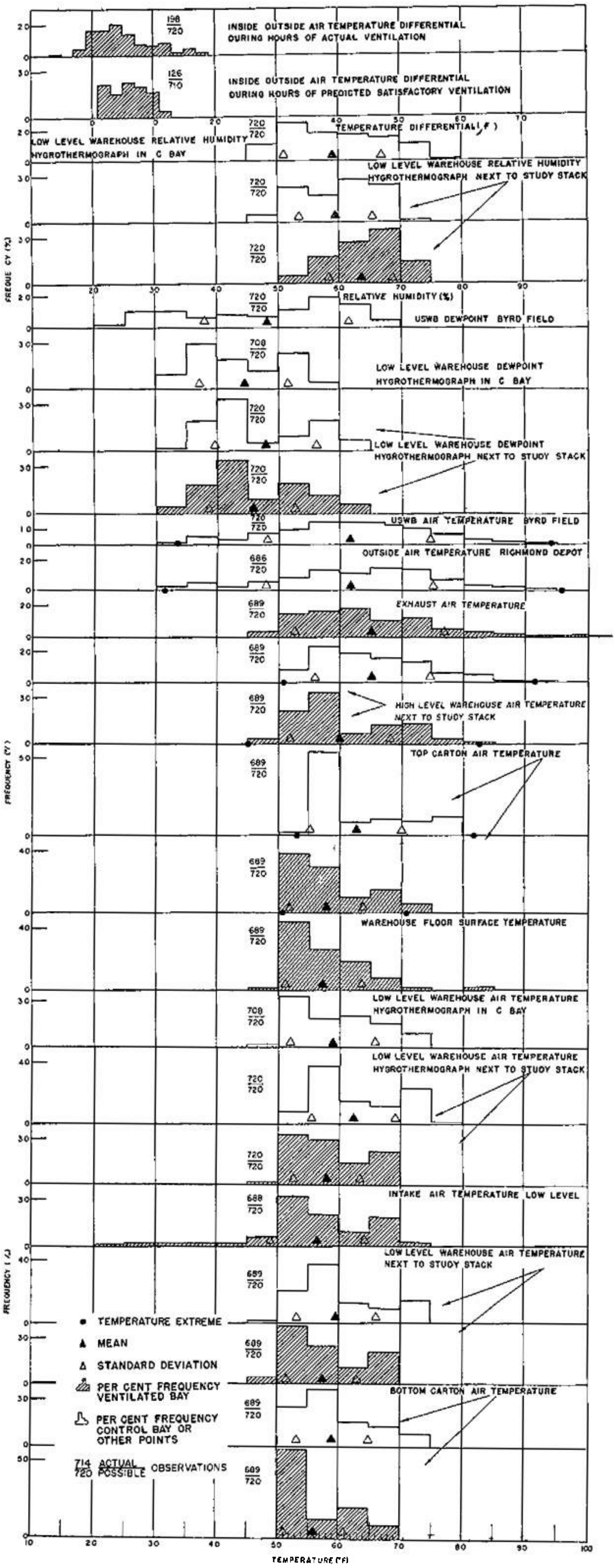

Figure 37. Frequencies, monthly means, and standard deviations of hourly observations for April, 1957.

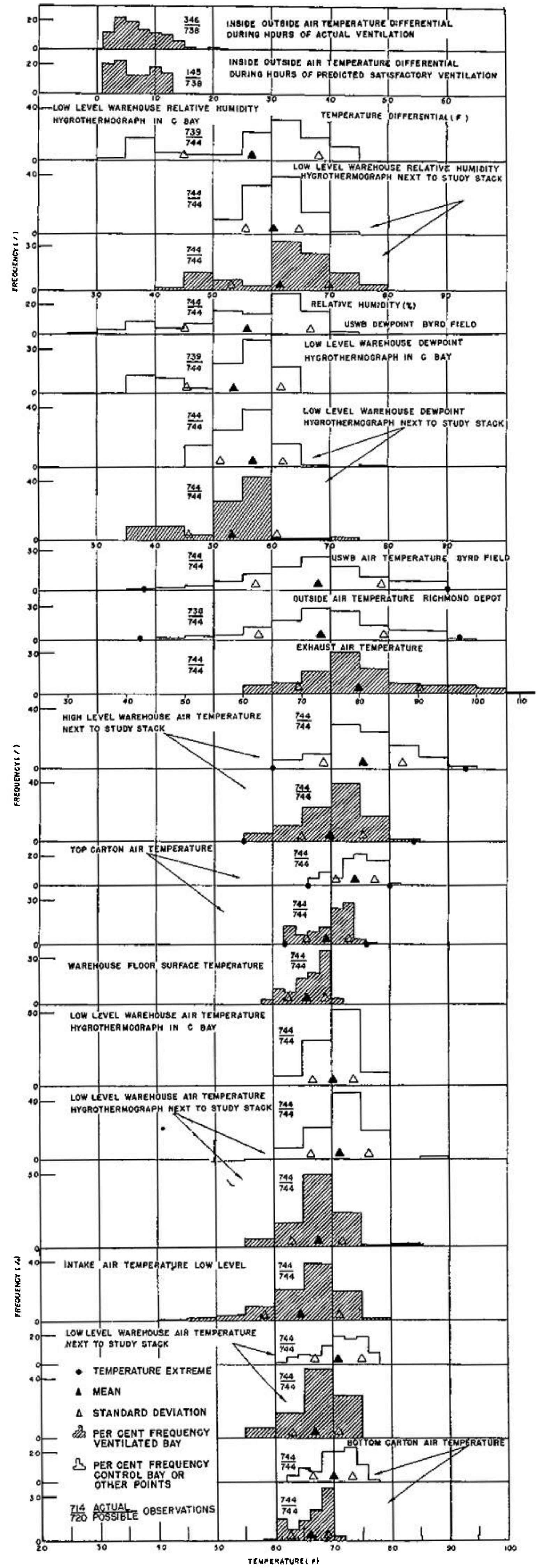

Figure 38. Frequencies, monthly means, and standard deviations of hourly observations for May, 1957

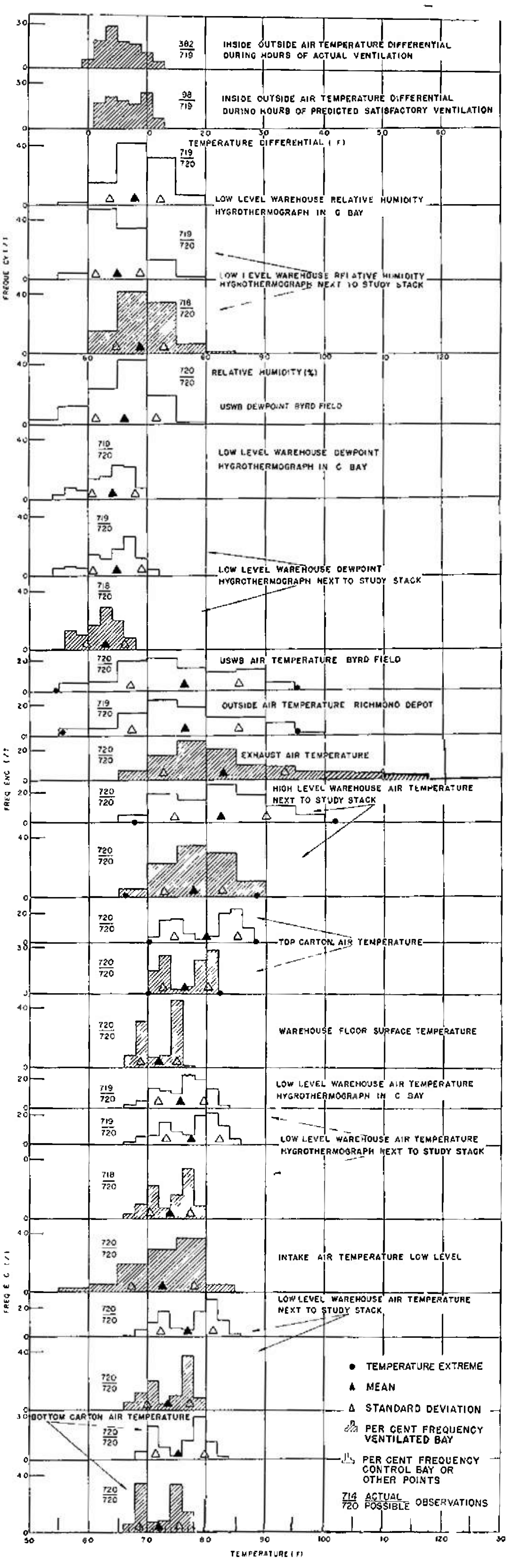

Figure 39 Frequencies, monthly means, and standard deviations of hourly observations for June, 1957

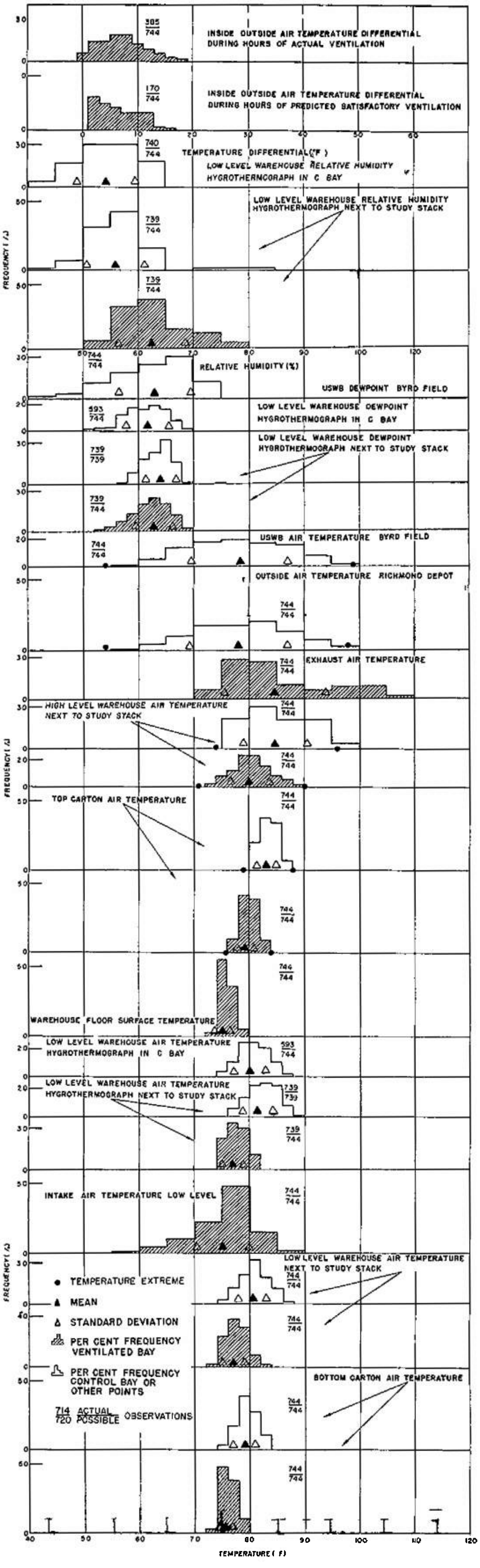

Figure 40. Frequencies, monthly means, and standard deviations of hourly observations for July, 1957.

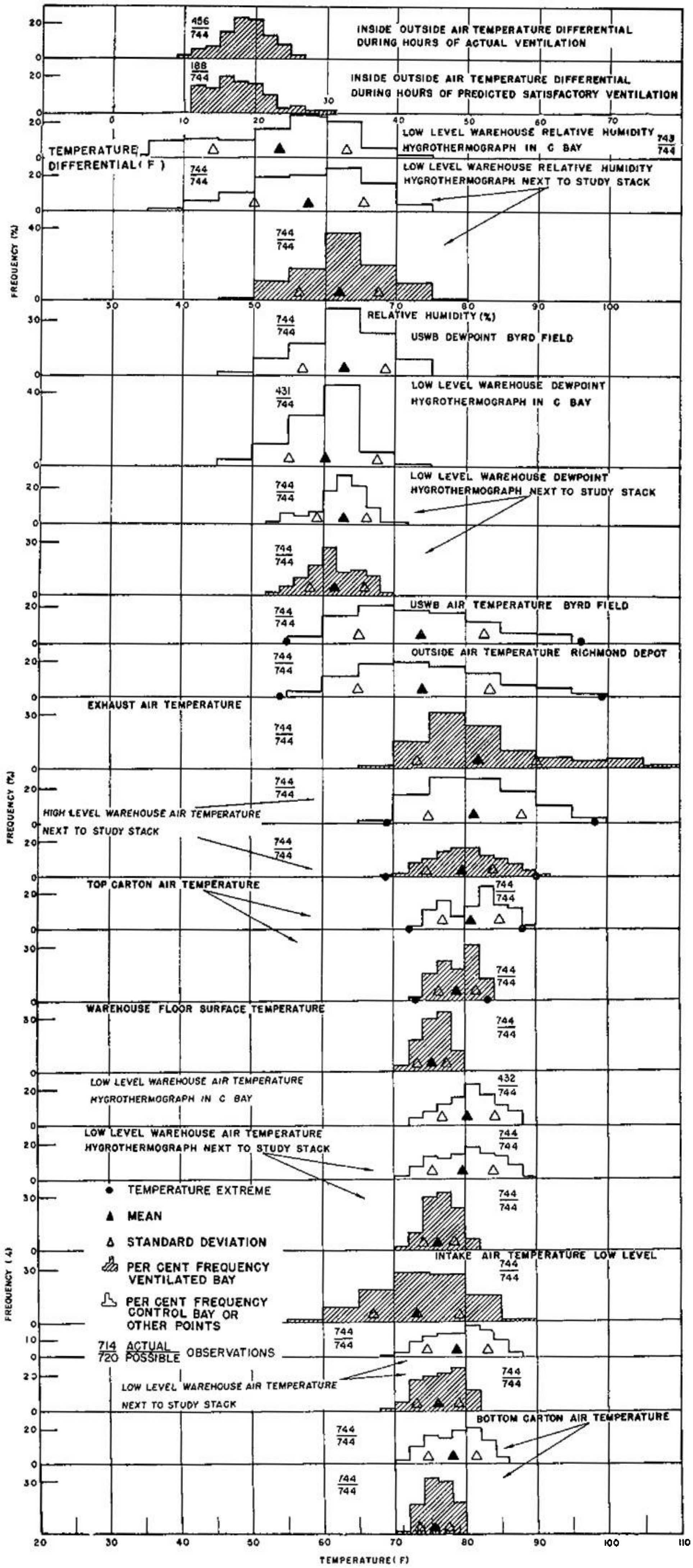

Figure 41 Frequencies, monthly means, and standard deviations of hourly observations for August, 1957

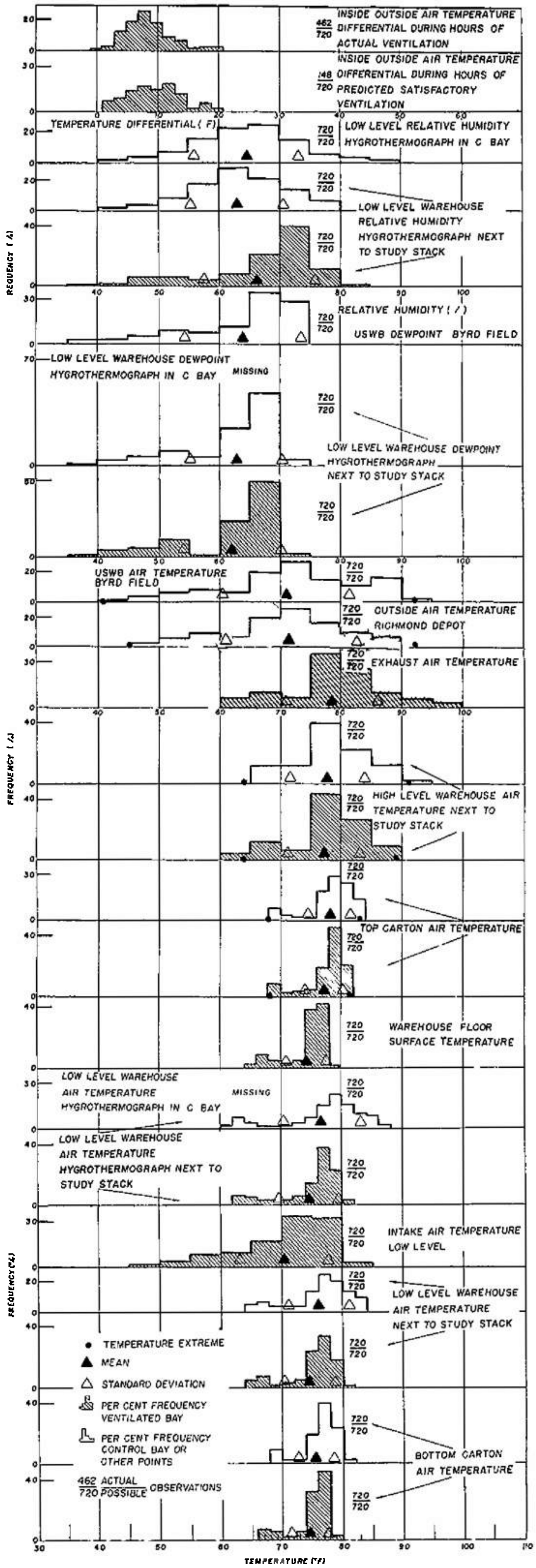

Figure 42. Frequencies, monthly means, and standard deviations of hourly observations for September, 1957.

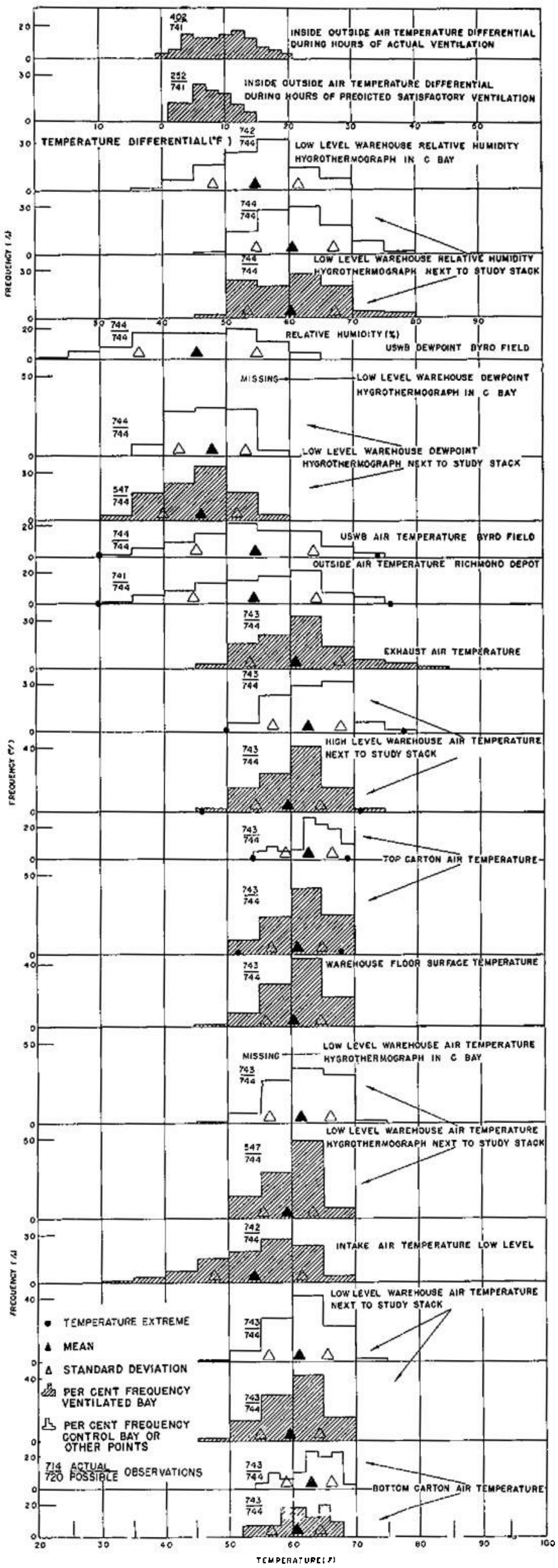

Figure 43 Frequencies, monthly means, and standard deviations of hourly observations for October, 1957.

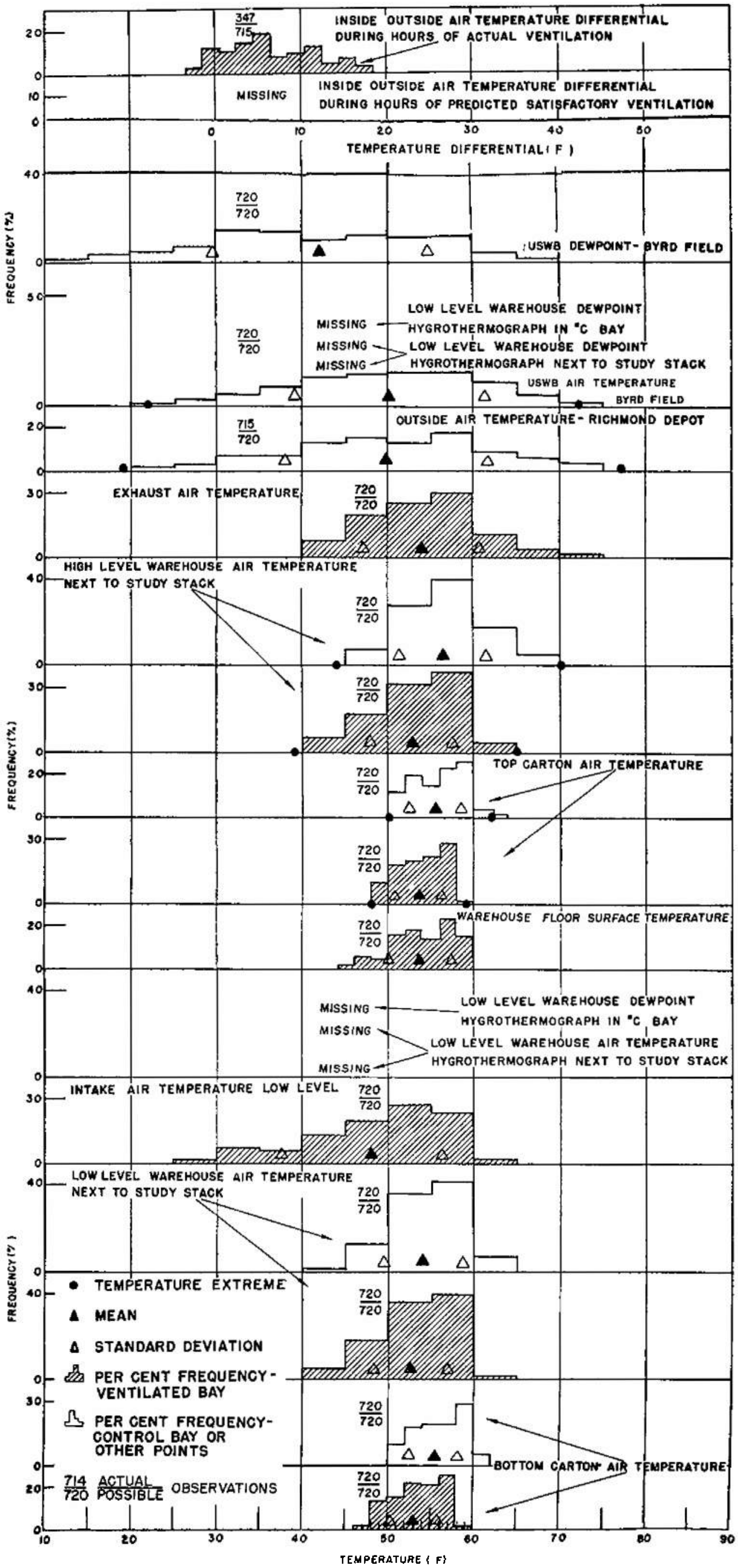

Figure 44. Frequencies, monthly means, and standard deviations of hourly observations for November, 1957

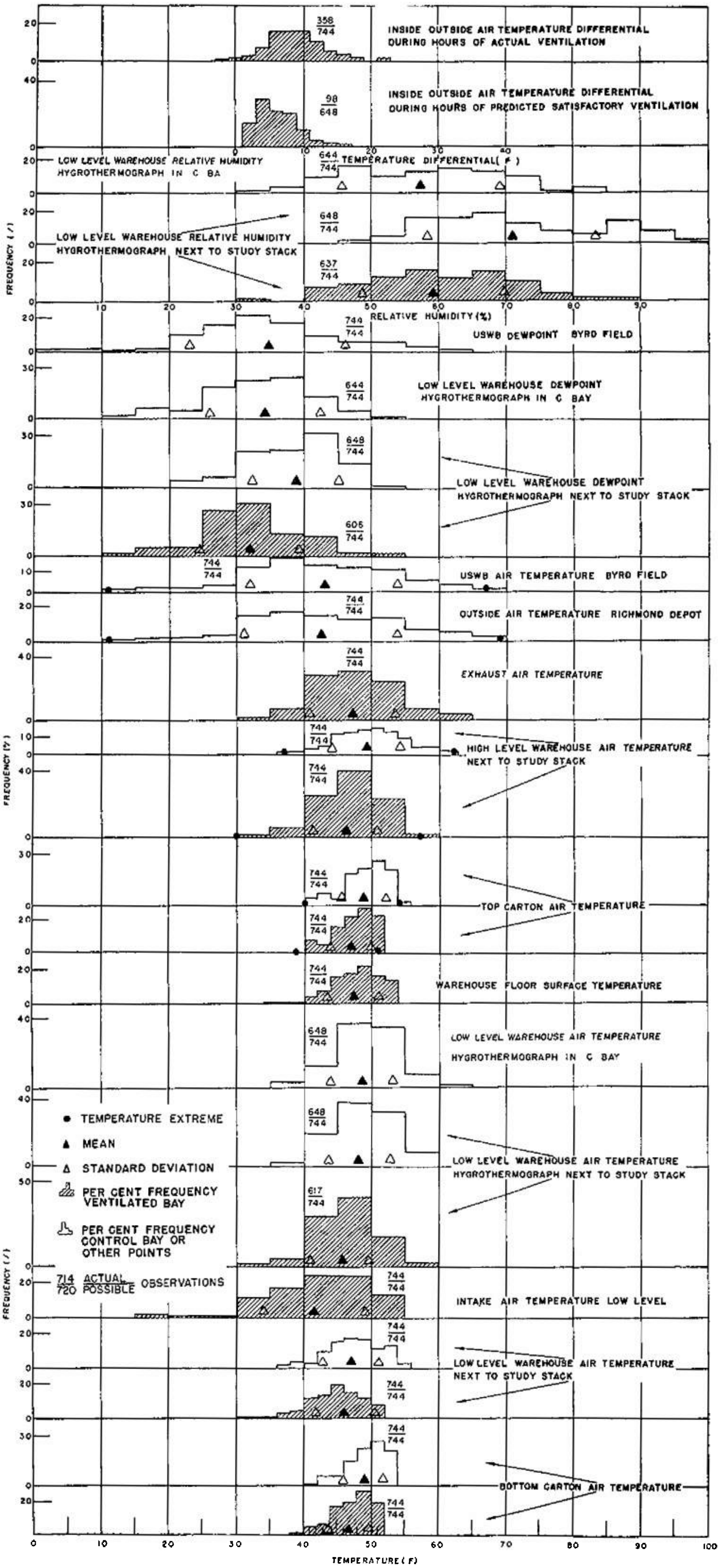

Figure 45. Frequencies, monthly means, and standard deviations of hourly observations for December, 1957

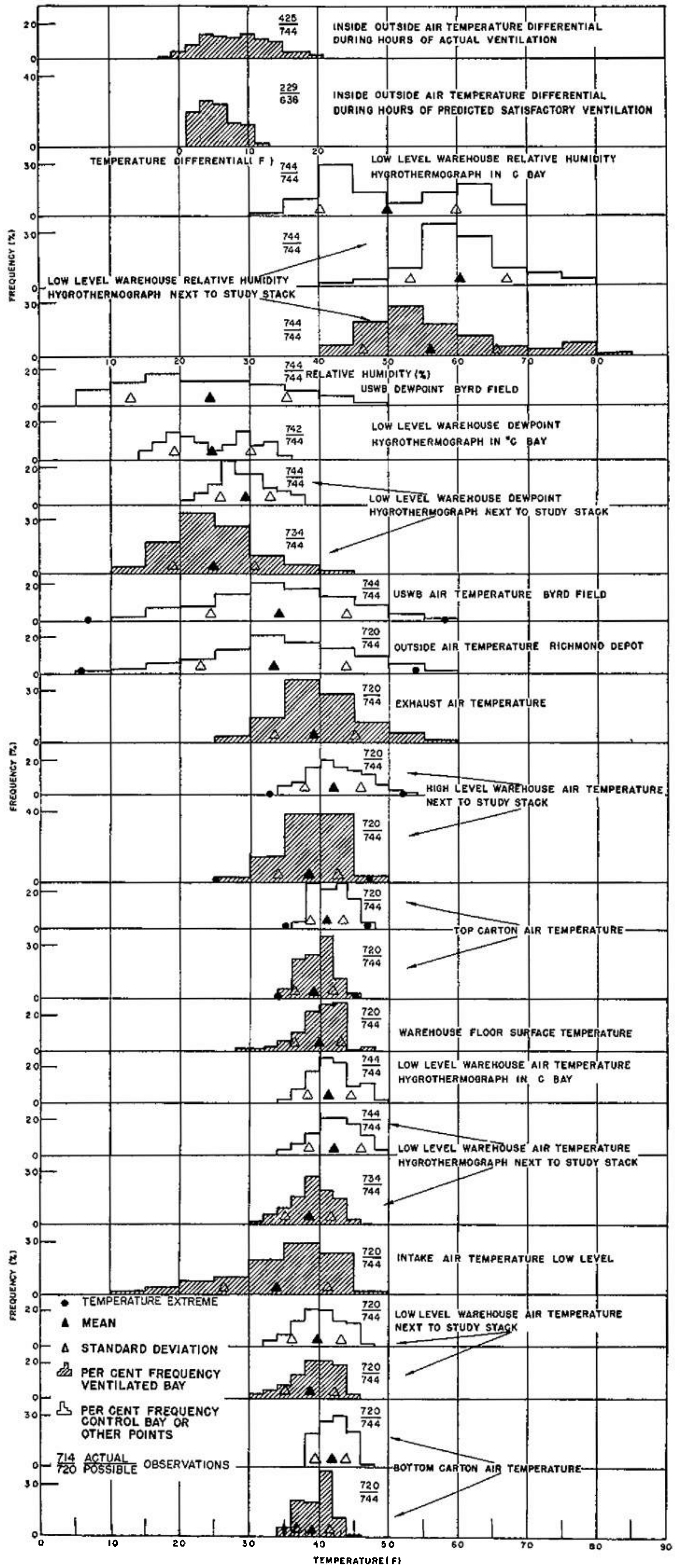

Figure 46. Frequencies, monthly means, and standard deviations of hourly observations for January, 1958

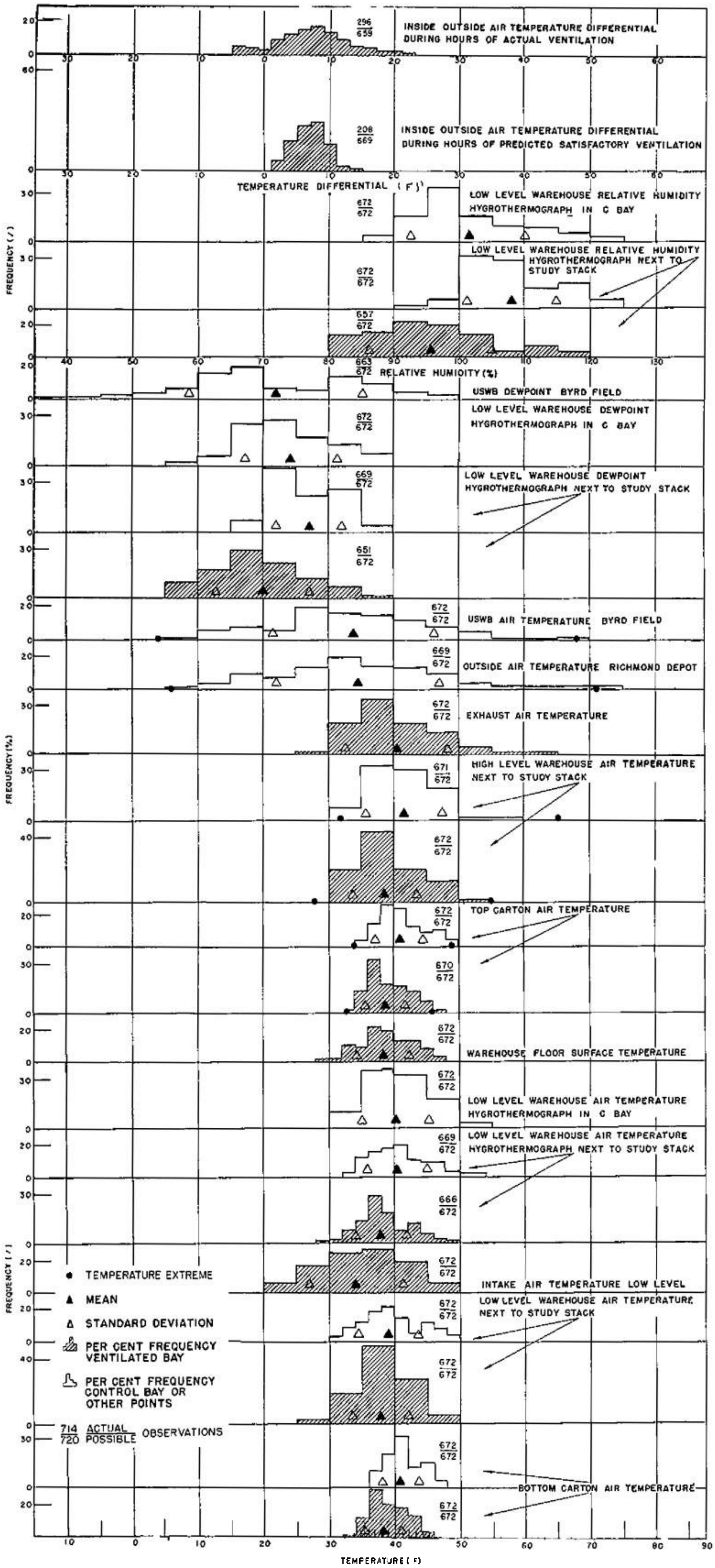

Figure 47 Frequencies, monthly means, and standard deviations of hourly observations for February, 1958

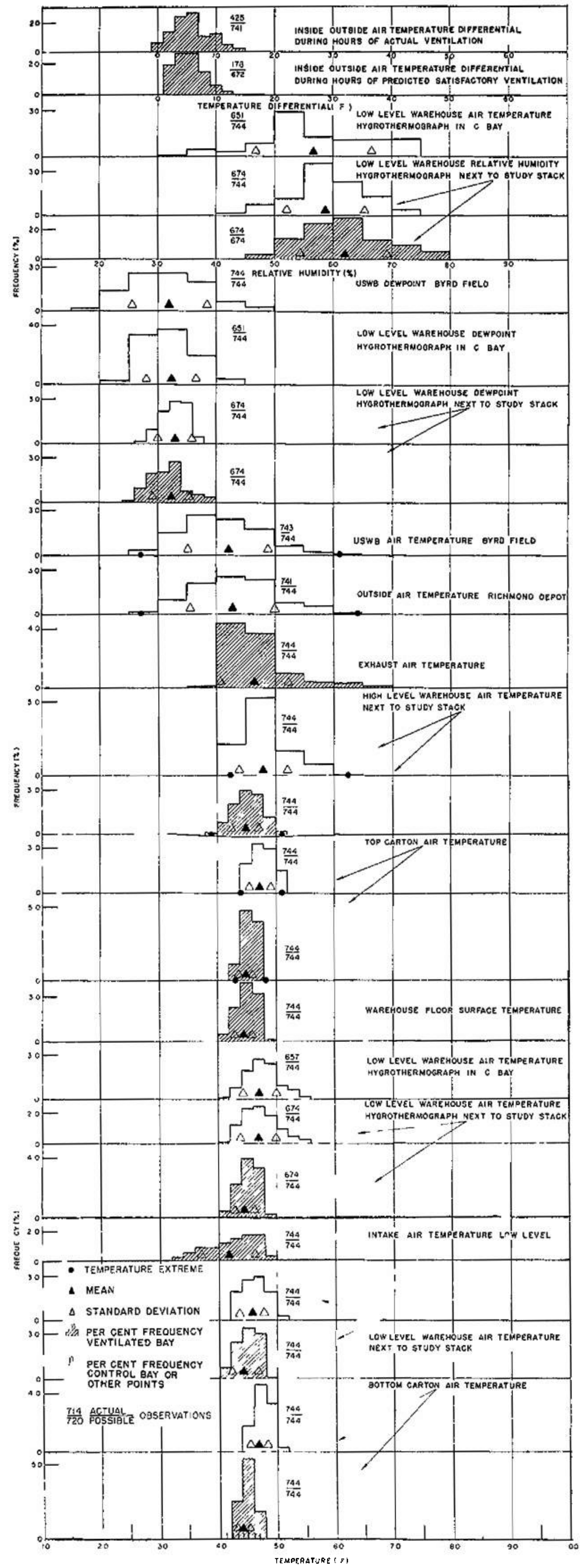

Figure 48 Frequencies, monthly means, and standard deviations of hourly observations for March, 1958

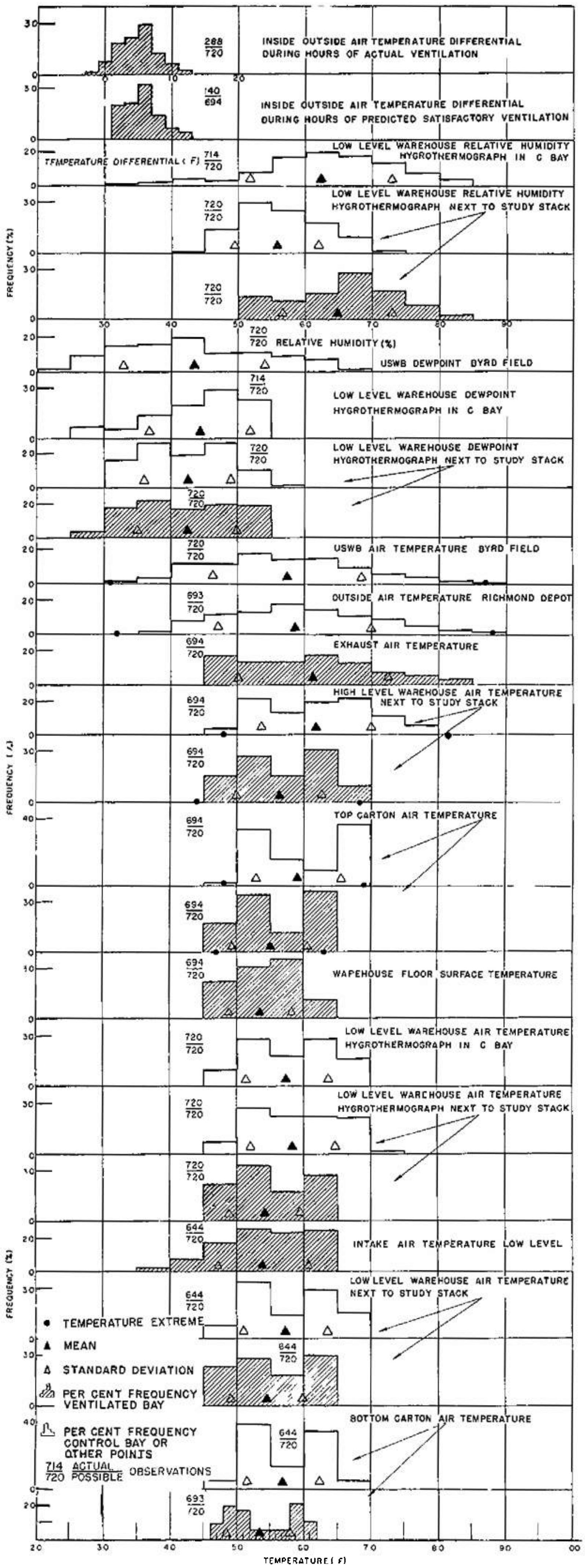

Figure 49 Frequencies, monthly means, and standard deviations of hourly observations for April, 1958

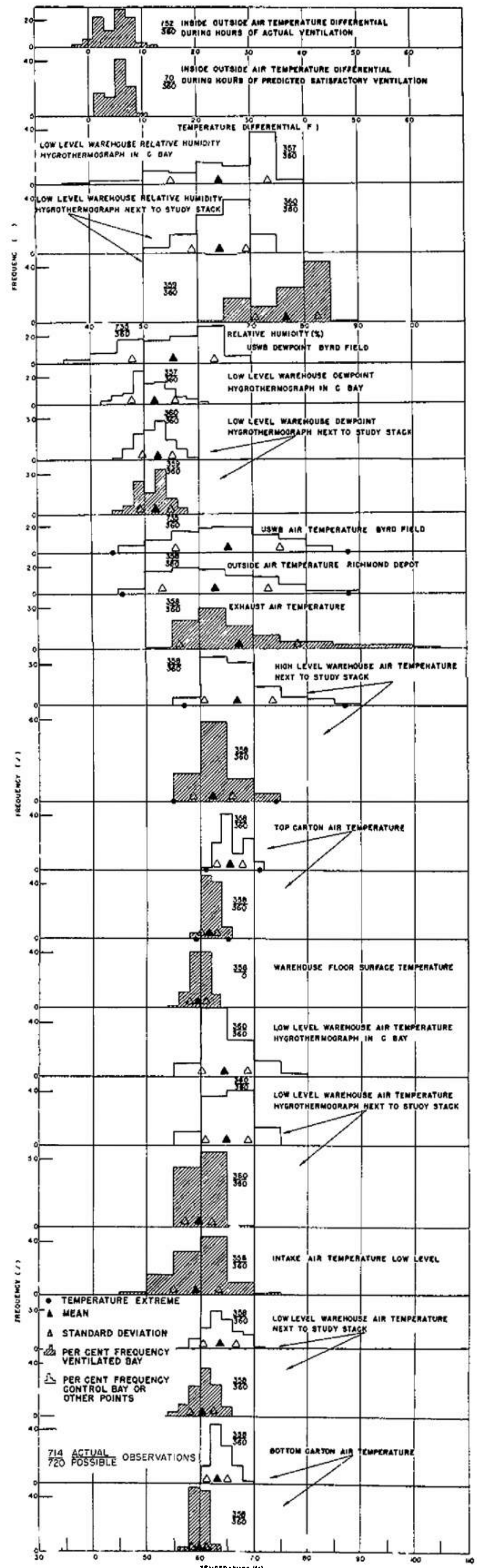

Figure 50. Frequencies, monthly means, and standard deviations of hourly observations for May, 1958.

APPENDIX C

Computation of effective monthly mean temperature from temperature frequency - Tables LXXX-LXXXII

Table LXXX

Computation of Effective Mean Temperature from Percentage Frequency of Temperature
November 1956 - Top Carton Air Temperature - Control Bay
Temperature (°F)

	47-8	49-0	51-2	53-4	55-6	57-8	59-0	61-2	63-4	65-6	67-8	69-0	Total
Percentage Frequency (%)	8	14	3	4	9	18	12	5	7	6	9	4	99
Degradation Rate at T[a]	0 41	0 45	0 48	0 52	0 56	0 61	0 65	0.71	0 76	0 82	0 89	0.96	
Total Degradation at T[b]	3 30	6 24	1 44	2.08	5 05	10 91	7 85	3 54	5.35	4 95	8 01	3 85	62 57
Mean Degradation Rate[c]	0 63												
Effective Mean Temperature[d]	57.8												
Arithmetic Mean Temperature	56 7												
Difference	1 1												

[a]Relative degradation rate at mean temperature of the class interval as a fraction of degradation rate at 70°F, based on Q_{10} of 2

[b]Relative degradation times percentage frequency

[c]Total degradation at all temperatures divided by total frequency.

[d]Temperature corresponding to mean degradation rate

Table LXXXI

Computation of Effective Mean Temperature from Percentage Frequency of Temperature[a]
April 1957 - Top Carton Air Temperature - Control Bay
Temperature (^{o}F)

	55-6	57-8	59-0	61-2	63-4	65-6	67-8	69-0	71-2	73-4	75-6	77-8	Total
Percentage Frequency (%)	4	27	24	5	4	3	5	3	1	5	10	7	98
Degradation Rate at T	0 56	0 61	0 65	0 71	0 76	0 82	0 89	0 96	1 04	1 12	1 21	1 31	
Total Degradation at T	2 24	16 36	15 71	3.54	3 06	2 47	4 45	2.89	1 04	5 62	12 12	9 16	78 7
Mean Degradation Rate	0 79												
Effective Mean Temperature	63 8												
Arithmetic Mean Temperature	62 8												
Difference	1 0												

[a] See Table LXXX for computation method

Table LXXXII

Computation of Effective Mean Temperature from Percentage Frequency of Temperature[a]
April 1958 - Top Carton Air Temperature - Control Bay
Temperature (^{o}F)

	49-0	51-2	53-4	55-6	57-8	59-0	61-2	63-4	65-6	67-8	69-0	Total
Percentage Frequency (%)	2	7	21	12	4	7	4	3	12	22	6	100
Degradation Rate at T	0.44	0.48	0 52	0.56	0 61	0 65	0.71	0 76	0.82	0 89	0 96	
Total Degradation at T	0.89	3 36	10 92	6 73	2 42	4.58	2.83	2.29	9 89	19.59	5 78	69 28
Mean Degradation Rate	0 69											
Effective Mean Temperature	60 5											
Arithmetic Mean Temperature	59.2											
Difference	1 3											

[a]See Table LXXX for computation method

APPENDIX D

Frequency of actual and predicted satisfactory ventilation by months and for total periods - Tables LXXXIII-LXXXVIII.

Table LXXXIII

1956
Frequency of Actual Ventilation
(% of Total Hours of Actual Ventilation)

Temperature Differential (°F)[a]	Jan - Jul[b]	Aug	Sep	Oct	Nov	Dec[c]	Year
23-24			1	2			1
21-22			2	2	2		2
19-20			4	2	12		5
17-18			6	4	14		7
15-16		5	6	4	14	2	7
13-14		10	9	7	9	12	9
11-12		19	14	10	9	16	12
9-10		31	24	9	12	8	15
7-8		20	18	17	7	5	14
5-6		6	10	18	7	6	11
3-4		2	2	11	6	5	6
1-2		0		11	4	15	5
-1 to 0		2			2	12	1
-3 to -2		1				12	1
-5 to -4						1	
Percentage of hours when $\Delta T \geq 9$ F		65	66	40	72	38	58
Number of hours of actual ventilation		164	382	383	389	78	1396
Number of hours of possible ventilation[d]		360	719	741	720	144	2684
Percentage ratio of number of hours of actual to number of hours of possible ventilation							52.1%

[a]High level warehouse air temperature minus outside air temperature [b]Data missing. [c]1 Dec to 6 Dec - total of 144 hours only

[d]Includes all hours of all days during which ventilation was practiced part of the day and temperature recordings were being made of both inside and outside air temperature.

Table LXXXIV

1956
Frequency of Predicted Satisfactory Ventilation
Frequency of Hours when all Conditions for Satisfactory Ventilation were Fulfilled
(% of Total Hours of Predicted Satisfactory Ventilation per Period)

Temperature Differential (°F)[a]	Jan-May[b]	Jun	Jul	Aug	Sep	Oct	Nov	Dec[c]	Year
19-20					2				
17-18		1	2	4	6		5		3
15-16		20	7	2	7	4	13	7	9
13-14		12	10	16	12	12	11	14	12
11-12		14	14	12	16	16	13	18	14
9-10		11	19	16	18	13	14	11	15
7-8		11	12	7	11	22	14	7	13
5-6		14	10	11	18	16	8	11	12
3-4		6	12	16	5	10	8	4	9
1-2		11	15	13	4	6	12	26	10
Percentage of hours when $\Delta T \geq 9°F$		58	52	50	61	45	56	50	53
			Total Hours with Each Condition						
1 Outside air temp. less than high level warehouse temp (hrs)			561	488	614	631	592	69	2955
2 USWB dewpoint less than control bay dewpoint (hrs)			299	253	282	305	487	283	1909
3 Outside air temp greater than control bay dewpoint (hrs)			649	573	662	659	536	143	3222

(cont'd)

Table LXXXIV (cont'd)

Total Hours with Each Condition

Temperature Differential (^{o}F)[a]	Jan-May[b]	Jun	Jul	Aug	Sep	Oct	Nov	Dec[c]	Year
4. Condition 1 & 2 (hrs)			224	143	241	260	421	28	1317
5. Condition 1, 2, & 3 (hrs)			156	133	186	193	254	27	949
Total hours of simultaneous temperature and humidity observations									3629
Percentage ratio of number of hours during which all three conditions are met to total hours									26 2%

[a]High level warehouse air temperature minus outside air temperature

[b]Data missing

[c]1 Dec to 6 Dec - total of 144 hours only.

Table LXXXV

1957
Percentage Frequency of Actual Ventilation
(% of Total Hours of Actual Ventilation)

Temperature Differential (°F)[a]	Jan[b]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
21-22												2	
19-20					1				2	1	2	0	1
17-18		3		1	0		1		2	4	6	2	2
15-16		9	2	4	1		2	2	1	6	4	4	3
13-14		11	6	1	6	1	5	8	6	12	12	6	7
11-12		22	9	8	10	4	8	13	8	16	9	12	11
9-10		20	9	6	11	10	12	22	17	14	7	18	14
7-8		12	19	7	13	16	19	23	25	12	18	18	18
5-6		8	18	13	19	17	19	15	18	12	14	18	16
3-4		4	14	20	22	28	14	7	12	14	10	9	14
1-2		4	10	16	12	18	14	6	2	4	11	4	9
-1 to 0		2	6	16		5	5	2	1	2	2	2	3
-3 to -2		1	2	4								1	
-5 to -4				2	0								
-7 to -6				1	1								
Percentage of hours when $\Delta T \geq 9°F$		65	26	20	29	15	28	45	36	53	40	44	38
Number of hours of actual ventilation		211	244	198	346	382	385	456	462	402	347	358	3791
Number of hours of possible ventilation[c]		456	744	720	738	719	744	744	720	741	715	744	7785
Percentage ratio of number of hours of actual to number of hours of possible ventilation													48 9%

[a]High level warehouse air temperature minus outside air temperature

[b]Data missing

[c]Includes all hours of all days during which ventilation was practiced part of the day and temperature recordings were being made of both inside and outside air temperature

Table LXXXVI

1957
Frequency of Predicted Satisfactory Ventilation
Frequency of Hours when all Conditions for Satisfactory Ventilation were Fulfilled
(% of Total Hours of Predicted Satisfactory Ventilation per Period)

Temperature Differential (^{o}F)[a]	Jan[b]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
19-20									3				
17-18									5				
15-16							1	4	2			1	1
13-14			3				2	2	11	5		2	3
11-12		6	4	4	14	6	12	10	18	10		3	9
9-10		20	14	16	18	23	12	16	14	17		10	16
7-8		20	28	20	12	15	12	17	17	19		20	19
5-6		24	20	22	12	18	16	20	13	23		21	19
3-4		10	18	15	22	20	19	14	9	11		28	16
1-2		17	11	21	20	16	24	15	7	11		14	15
Percentage of hours when $\Delta T \geq 9^{o}F$		26	21	20	32	29	27	32	53	32		16	29
Total Hours with Each Condition													
1 Outside air temp. less than high level whse temp. (hrs)		458	483	298	451	466	431	589	634	572		491	4873
2 USWB dewpoint less than control bay dewpoint (hrs)		340	517	315	297	167	342	306	179	481		426	3370
3 Outside air temp. greater than control bay dewpoint (hrs)		496	572	620	675	708	708	698	692	595		396	6160

(cont'd)

Table LXXXVI (cont'd)

Total Hours with Each Condition

Temperature Differential (^{o}F)[a]	Jan[b]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
4 Condition 1 & 2 (hrs)		286	350	192	207	104	201	221	170	377		328	2436
5 Condition 1, 2, & 3 (hrs)		138	238	126	145	98	170	188	148	252		98	1601
Total hours of simultaneous temperature and humidity observations													7190
Percentage ratio of number of hours during which all three conditions are met to total hours													21 3%

[a]High level warehouse air temperature minus outside air temperature

[b]Data missing

Table LXXXVII

1958
Percentage Frequency of Actual Ventilation
(% of Total Hours of Actual Ventilation)

Temperature Differential (°F)[a]	Jan	Feb	Mar	Apr	May	Jun - Dec[b]	Year
21-22		1					
19-20	2	2					1
17-18	4	2					1
15-16	4	4					2
13-14	10	5	2				4
11-12	11	9	4	2	1		6
9-10	14	13	12	6	4		11
7-8	12	17	10	12	22		14
5-6	13	15	26	29	28		21
3-4	14	12	24	21	12		17
1-2	8	9	13	18	22		13
-1 to 0	4	3	6	7	6		5
-3 to -2	1	4		1	2		2
-4 to -3		5					1
Percentage of hours when $\Delta T \geq 9^{\circ}F$	45	36	18	8	5		25
Number of hours of actual ventilation	425	296	425	288	152		1586
Number of hours of possible ventilation[c]	744	669	741	720	360		3236
Percentage ratio of number of hours of actual to number of hours of possible ventilation							49.1%

[a]High level warehouse air temperature minus outside air temperature

[b]Data missing.

[c]Includes all hours of all days during which ventilation was practiced part of the day and temperature recordings were being made of both inside and outside air temperature.

Table LXXXVIII

1958
Frequency of Predicted Satisfactory Ventilation
Frequency of Hours when all Conditions for Satisfactory Ventilation were Fulfilled
(% of Total Hours of Predicted Satisfactory Ventilation per Period)

Temperature Differential (°F)[a]	Jan	Feb	Mar	Apr	May	Jun - Dec[b]	Year
13-14		1					
11-12	2	3	3	4			3
9-10	13	16	6	6	3		10
7-8	14	29	15	14	22		19
5-6	24	27	28	32	42		28
3-4	26	18	28	21	14		22
1-2	20	6	20	20	17		16
Percentage of hours when $\Delta T \geq 9^{o}F$	15	20	9	10	3		13
	Total Hours with each Condition						
1 Outside air temp. less than high level warehouse temp (hrs)	537	471	480	302	178		1968
2 USWB dewpoint less than control bay dewpoint (hrs)	550	440	339	314	156		1799
3. Outside air temp greater than control bay dewpoint (hrs)	489	501	653	687	329		2659

(cont'd)

Table LXXXVIII (cont'd)

Total Hours with each Condition

Temperature Differential (°F)[a]	Jan	Feb	Mar	Apr	May	Jun - Dec[b]	Year
4 Condition 1 & 2 (hrs)	439	364	191	146	99		1239
5 Condition 1, 2, & 3 (hrs)	229	206	177	140	70		822
Total hours of simultaneous temperature and humidity observations							3032
Percentage ratio of number of hours during which all three conditions are met to total hours							27 1%

[a]High level warehouse air temperature minus outside air temperature

[b]Data missing

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13 ABSTRACT

This report contains the detailed analysis of the frequencies, means, and standard deviations of temperature observations made at sixteen positions in the storage area and in food containers in two bays (non-ventilated and night ventilated) of an Army warehouse at Richmond, Virginia, during a three year period.

Hourly temperatures at all points are reported for several selected hottest days.

Temperature distributions by months and for the total year at each position are given in tabular and graphical form. Thus, if an empirical temperature degradation relation is known for a given food, the expected storage life at this warehouse may be predicted

Storage monthly mean temperatures were found to be highly significantly correlated with outside air mean temperatures, facilitating prediction of effective mean storage temperatures for laboratory simulation where only ambient data are known.

The work of Dr. Arthur V. Dodd of Earth Sciences Laboratory has demonstrated that similar predictive relations hold between mean storage air and mean warehouse air temperature for 15 US Army warehouses of various types and locations. Therefore, storage life predictions may be made for other warehouses if the food degradation-temperature relationship is known.

(cont'd on attached)

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Analysis	8					
Frequencies	9		6			
Mean	9		6			
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Temperature	9		6			
Warehouses	9		6			
Food storage	4		7			
Ventilation fans			6			
Thermal degradation	4		7			
Food	4		7			

13 Abstract (cont'd)

Using only two one-horsepower exhaust fans, the effect of combined night air ventilation and insulation was shown to be somewhat small (4.25 F° difference in mean storage air temperature) but for one year 18% increase in storage life of an average food would be predicted as a result.

It was predicted that the installation of more fans would greatly increase the cooling and resultant food storage life. Increasing the horsepower without increase in number of fans would be less effective.